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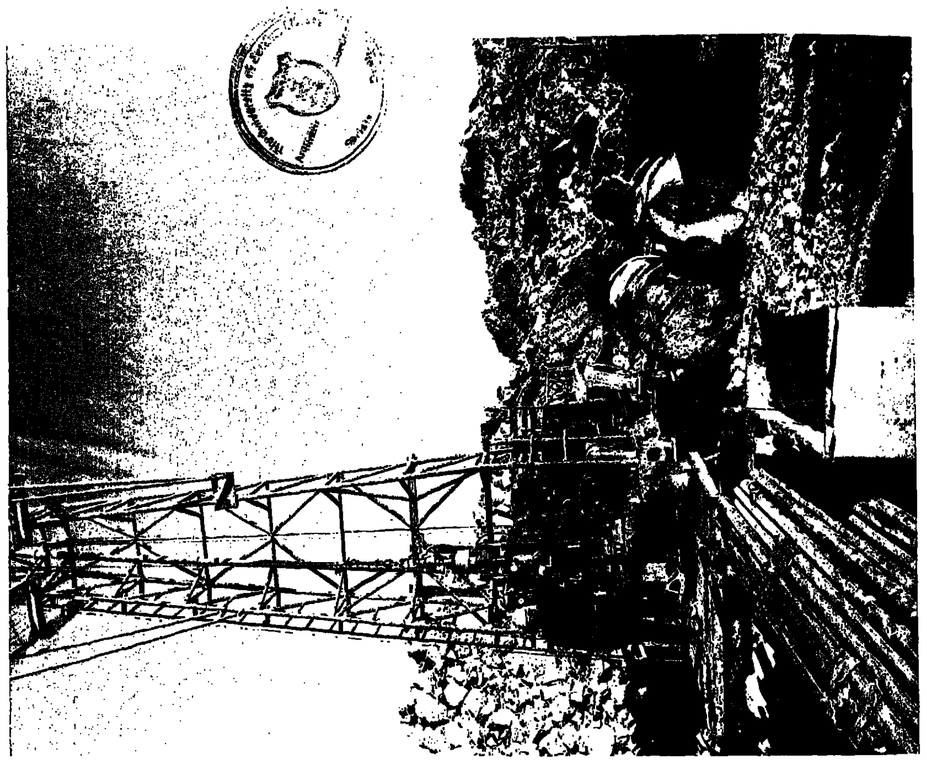

The VGP News, page 722

Eos, Transactions, American Geophysical Union Vol. 65, No. 39, Pages 721–728 September 25, 1984

Tectonophysics

8150 Tectonophysics (Plate tectonics)
NON-COHESIVE CRITICAL COULOMB WEDGES: AN EXACT SOLUTION
F. A. Dahlen (Department of Geological and Geophysical Sciences, Princeton University, Princeton, New Jersey 08544)

Active fold-and-thrust belts or subsurface accretionary complexes can be modeled as critically tapered wedges of material on the verge of Coulomb failure everywhere, overlying a basal decollement where frictional sliding is occurring. Ignoring cohesion, the four strength parameters needed to describe a critical Coulomb wedge are its internal and basal coefficients of friction μ and μ_b and its internal and basal Hubbert-Rubey fluid-pressure ratios λ and λ_b. An exact relation between the surface slope α and basal dip β of a non-cohesive critical wedge with uniform properties is derived. The state of stress within such a wedge has the same orientations everywhere, and is constant if β is and vice-versa. A coefficient of internal friction $\mu = 1.1$ is consistent with the known surface slope, basal dip and pore-fluid pressures in the active fold-and-thrust belt of western Taiwan, assuming Byerlee's law $\mu_b = 0.85$ is valid on the base. The wide variety of tectonic styles observed to occur along convergent margins, including subduction erosion, active accretion, subduction without accretion and even extension and shear faulting, may be controlled by relatively small spatial or temporal variations in either μ_b or λ_b.

J. Geophys. Res., B, Paper 4B0880

8150 Plate tectonics
PREFERENTIAL RIFTING OF CONTINENTS: A SOURCE OF DISPLACED TERRANES
Gregory E. Vink (Department of Geological and Geophysical Sciences, Princeton University, Princeton, New Jersey, 08544), W. Jason Morgan and Wu-Ling Zhao

Lithospheric rifting, while prevalent in the continents, rarely occurs in oceanic regions. To explain this preferential rifting of continents we compare the total strength of different lithospheres by separating the limits of lithospheric stress with depth. Comparisons of total strength indicate that continental lithosphere is weaker than oceanic lithosphere by about a factor of three. Also, a thickened crust can halve the total strength of normal continental lithosphere. Because the weakest area acts as a stress guide, any rifting close to an ocean-continent boundary would prefer a continental pathway. This results in the formation of small continental fragments or microplates, which once accreted back to a continent during subduction are seen as displaced terranes. In addition, the large crustal thicknesses associated with suture zones could, ironically, make such areas likely locations for future rifting episodes. This results in the tendency, described as the Wilson Cycle, of new oceans to open along the sutures where a former ocean had closed. (Rifting, displaced terranes, lithospheric strength, Wilson Cycle).

J. Geophys. Res., B, Paper 4B0596

8150 Plate tectonics
STRUCTURAL TRENDS IN THE NORTHERN RED SEA
Y. Hart (Oceanography department, Texas A&M University, College Station TX 77843), J.K. Hall.

The northern Red Sea is underlain by a series of Plio-Pleistocene sedimentary strata that unconformably overlies respectic series of late Miocene age. A series of boinal rifts and concentric diapirs, trending approximately N-S, were recently discovered in that region between lat. 28°30'N and 29°N. The rifts are up to 40 km long, 7 km wide, and the diapirs commonly second along the rifts' boundary faults. The diapirs stem from the late Miocene evaporites, therefore it is proposed that the discerned structural trends were developed during the Plio-Pleistocene.

The reconstructed structural patterns deviate considerably from the NW-SE structural trends that prevail in the central Red Sea as well as in the faults that border the northern Red Sea and the Gulf of Suez. The tectonic activity that formed the Suez rift in the middle-late Miocene was not rejuvenated there during the Plio-Pleistocene and the new data indicates that the axis of the tectonic extension at the northern Red Sea jumped to show a northward orientation. It is suggested that an incipient spreading center extends from the Red Sea northwards to the Gulf of Elat and the Dead Sea rift. (Red Sea rifts, diapirs, spreading center jump).

J. Geophys. Res., B, Paper 4B1029.

News

Covering for GOES

In the wake of last July's failure of the Geostationary Operational Environmental Satellite (GOES 5) weather satellite over the eastern part of the United States, managers at the National Oceanic and Atmospheric Administration (NOAA) are trying to keep the weather data flowing to satellite users around the country. The geosynchronous satellite, one of two GOES spacecraft stationed over American longitudes, lost its imaging capability on July 29 (*Eos*, August 21, 1984, p. 483).

Following the failure, the companion GOES-West satellite was shifted from its 135°W station to a more central position over the United States (98°W) so as to cover the eastern part of the country as much as possible. Now, says William Callicott, deputy director of NOAA's Office of Satellite Data Processing and Distribution, the lone remaining U.S. geosynchronous weather satellite will be shifted around with the seasons. At the end of this hurricane season, sometime after November 15, GOES-West (or GOES 6, as it is officially called) will be moved from 98°W to 108°W, where it can better keep watch on winter storms in the northeastern Pacific. Then, in mid-April, after the tornado season, it will be moved back to the central location of 98°W.

In the meantime, NOAA is providing weather encoded facsimile (WEFAX) data from non-U.S. geosychronous satellites (via telephone land lines) to users who normally rely on the GOES data. The European METEOSAT, stationed at 0° longitude, can "see" as far west as 50° and so fills part of the GOES data gap in the Atlantic Ocean. Once the Japanese Geostationary Meteorological Satellite (GMS) is operational in October, it will cover the western Pacific, including Hawaii. By providing WEFAX data from these satellites for areas to the east and west of the North American continent, NOAA hopes to minimize the impact of the GOES failure until a replacement satellite can be launched.

The good news is that the wait for that replacement may be shorter than was previously expected. The spacecraft's builder, Hughes Aircraft Co., hopes to accelerate the production schedule for the next GOES satellite by more than 6 months, according to Callicott. "They're taking all the slack out [of the schedule]," he told *Eos*, so that, if everything goes according to "almost a total success schedule," with no unforseen problems, the satellite would be ready for launch by early autumn of 1985 instead of May 1986.

ESA/NASA Solar Polar Mission Renamed Ulysses

The International Solar Polar Mission (ISPM), a joint project between the European Space Agency (ESA) and NASA, has been renamed "Ulysses." The primary mission of the project, which has not changed with its name, is to investigate the properties of the solar wind, the structure of the sun/wind interface, the heliosphere magnetic field, the interplanetary magnetic field, the solar wind plasma, solar and galactic cosmic rays, and cosmic dust.

Scheduled for launch from the space shuttle in May 1986, the Ulysses mission will make a 14-month journey to Jupiter. That planet's gravitational effect will deflect the probe into a high-inclination orbit toward the sun. Reaching the sun about 2.5 years later, the satellite will take measurements over the sun's poles. The entire mission will last 5 years.

The mission's new name refers not only to Homer's mythological hero but also to Dante's description in "Inferno" of Ulysses' desire to explore "an uninhabited world behind the sun."

Glaciology Committee Formed

A committee has been formed to draft a science plan for U.S. involvement in a second deep drilling project on the Greenland Ice Sheet. The first meeting was held in Columbus, Ohio, on July 12, 1984. This committee is addressing two primary issues: (1) potential scientific and logistic involvement in a new multinational program and (2) the advancement of glaciological research in the United States through a science program in Greenland. The committee has received letters from U.S. scientists expressing support and interest in this deep drilling effort.

The members of this committee would be pleased to receive comments or ideas related to possible science programs utilizing the ice core, the borehole, or the logistics facilities at the drill site. The committee members are Ellen Mosley-Thompson (Chair), Institute of Polar Studies, Ohio State University, Columbus, OH 43210; Anthony J. Gow, U.S. Army CRREL, 72 Lyme Road, Hanover, NH 03755; Michael Herron, Schlumberger-Doll Research, Ridgefield, CT 06877; Kenneth C. Jezek, U.S. Army CRREL, 72 Lyme Road, Hanover, NH 03755; Barclay Kamb, Department of Earth and Planetary Sciences, California Institute of Technology, Pasadena, CA 91109; and Aslam Khalil, Oregon Graduate Center, Oregon State University, Beaverton, OR 97006.

Geophysicists

Charles Elachi has been named manager of the Earth and Space Sciences Division of the National Aeronautics and Space Administration's Jet Propulsion Laboratory (JPL) in Pasadena, Calif. He succeeds ***Moustafa Chahine***, who assumed the position of JPL chief scientist. Elachi, who joined JPL as a senior scientist in 1971, will continue as principal investigator on the Shuttle Imaging Radar (SIR) series.

Arnold L. Gordon, Professor of Geological Sciences at Columbia University's Lamont-Doherty Geological Observatory, has received the ninth Henry Bryant Bigelow Medal from the Trustees of the Woods Hole Oceanographic Institution in recognition of his 20 years of research in the Southern Ocean and, in particular, for his completion of the Southern Ocean Atlas. In the citation he was described as "the world expert on the physical oceanography of the Southern Ocean."

G. Ross Heath, formerly Dean of the College of Oceanography at Oregon State University, has joined the University of Washington as Dean of the College of Ocean and Fishery Sciences.

Jerome Namias, a research meteorologist at the Scripps Institution of Oceanography, has been awarded the Marine Technology Society's Compass Distinguished Achievement Award for 1984 "for significant contributions to the art and science of oceanography and marine technology." Associated with Scripp's Climate Research Group since 1968, Namias has been involved in long-term weather prediction research and forecasting since the early 1940's. From 1941 to 1964 he served as chief of the Extended Forecast Division of the U.S. Weather Bureau and from 1964 to 1966 as associate director of the National Meteorological Center.

Glenn E. Stout has been named executive director of the International Water Resources Association (IWRA), Urbana, Ill. Stout is currently director of the Water Resources Center at the University of Illinois Urbana-Champaign campus and editor-in-chief of the IWRA publication *Water International*. IWRA's new address is IWRA, University of Illinois, 208 North Romine St., Urbana, IL 61801 (telephone: 217-333-0536).

Alfred N. Fowler has become acting director of the National Science Foundation's Division of Polar Programs.

In Memoriam

Ralph M. Berry, 74, died August 22, 1984. A member of the Geodesy Section, he joined AGU in 1959.

Jürgen Henning Jilles, 58, died August 2, 1982. A member of the Tectonophysics Section, he joined AGU in 1978.

Geophysical Events

This is a summary of *SEAN Bulletin*, *9*(8), August 31, 1984, a publication of the Smithsonian Institution's Scientific Event Alert Network. The complete bulletin is available in the microfiche edition of *Eos* as a microfiche supplement or as a paper reprint. For the microfiche, order document E84–009 at $2.50 (U.S.) from AGU Fulfillment, 2000 Florida Avenue, N.W., Washington, DC 20009. For the paper reprint, order *SEAN Bulletin* (giving volume and issue numbers and issue date) through AGU Separates at the above address; the price is $3.50 for one copy of each issue number for those who do not have a deposit account, $2 for those who do; additional copies of each issue number are $1. Subscriptions to *SEAN Bulletin* are available from AGU Fulfillment at the above address; the price is $18 for 12 monthly issues mailed to a U.S. address, $28 if mailed elsewhere, and must be prepaid.

Volcanic Events

Kliuchevskoi (Kamchatka): Tephra ejection; lava flows; lahars.

Mayon (Philippines): Eruption clouds to 15 km; pyroclastic flows; lava flows.

Soputan (Indonesia): Ash eruption follows local seismicity.

Api Siau (Indonesia): Tephra ejection, lava flows, lahars; 20,000 evacuated.

Rabaul (New Britain): Earthquake swarms and slow inflation continue.

Manam (Bismarck Sea): Vulcanian explosions; glowing debris avalanches.

Ulawun (New Britain): Increased seismicity, then small ash clouds and glow.

Bagana (Solomon Islands): Lava production continues; SO_2-rich plume.

Langila (New Britain): Occasional ash emission; seismicity weak.

Home Reef (Tonga): Pumice from March-April eruption continues to drift north and west.

Krafla (Iceland): Eruption from 8.5-km fissure.

Etna (Italy): Lava production and ash-emission continue.

Lake Monoum (Cameroon): Poisonous gas from lake explosion kills 37.

Pacaya (Guatemala): Summit area lava production continues.

Mount St. Helens (Washington): Intense deformation, then extrusion of new lobe.

Long Valley (California): Seismicity at relatively low level and inflation modest since January 1983 swarm; U.S. Geological Survey says imminent eruption less likely.

Kilauea (Hawaii): Phase 24; high fountains; thin tephra blanket.

Veniaminof (Alaska): Vapor plumes, roaring noise, and felt earthquakes.

Atmospheric effects: 10 years of lidar data from Virginia summarized.

Kliuchevskoi Volcano, *Kamchatka Peninsula, U.S.S.R. (56.18°N, 160.78°E). All times are local (= UT + 12 hours).*

Eruptive activity which began in March (*Eos*, p. 425, July 3, 1984) continued through August. During periods of maximum activity, ash was ejected to 5 km and bombs to 1 km above the crater rim (summit elevation 4850 m). Lava flowed to the northwest, northeast, and southwest from the central crater; the largest flow advanced along the northwest valley to about 3 km above sea level and crossed a glacier, forming mud flows. A cinder cone has formed inside the central crater.

On August 17 between 0733 and 1027, high-resolution thermal infrared and visual images from polar orbiting weather satellites showed a plume extending about 200 km southeast from the volcano below about 6 km altitude. Soviet volcanologists confirmed these observations, reporting that on August 16–17 a 15-km-wide ash plume extended 200 km from the volcano.

Information Contacts: B. V. Ivanov, Institute of Volcanology, Piip Avenue 9, Petropavlovsk, Kamchatskii 683006 U.S.S.R.; Michael Matson, NOAA/NESDIS, Room 510, World Weather Building, Washington, D.C. 20233.

Soputan Volcano, *Sulawesi, Indonesia (1.11°N, 124.73°E). All times are local (= UT + 8 hours).*

A 5-hour explosive eruption occurred at Soputan on August 31. This was the first activity since the May 24–26 tephra ejection that deposited more than 10 cm of ash on a 75-km² area and forced two airports to close (*Eos*, p. 425, July 3, 1984).

Volcanological Survey of Indonesia (VSI) seismic instruments recorded a progressive increase in local seismicity beginning August 6. On August 14, a sequence of tremors appeared between 0400 and 0800, with amplitude increasing to 25 mm (at 2000 magnification). VSI issued a warning to civil authorities and an alert was put into effect on August 14. Seismicity continued August 15–25 with an irregular number of A- and B-type events, averaging 1–2 per day. From August 25 until the time of the eruption, seismicity totally stopped, increasing suspicion among VSI scientists that an eruption was possible.

The eruption started at 0709 on August 31 and lasted until about noon. An ash column rose to about 6 km and moved northeastward. Authorities and area residents were well prepared, and neither casualties nor an evacuation were reported. Press sources reported that the ash cloud could be seen from Manado, the provincial capital 80 km to the north. The ash cloud covered a large area and disrupted traffic on the Trans-Sulawesi highway.

On August 31 at 1457, a visible band image from the NOAA 7 polar orbiting satellite showed a plume extending about 450 km westward from the volcano. The plume was quite dense and about 120 km wide.

Information Contacts: Adjat Sudradjat, Director, Volcanological Survey of Indonesia, Diponegoro 57, Bandung, Indonesia; Michael Matson, NOAA/NESDIS, Room 510, World Weather Building, Washington, D.C. 20255; United Press International.

Krafla Caldera, *Myvatn Area, Iceland (65.73°N, 16.68°W). The following is a report from Karl Grönvold and Páll Einarsson.*

"After a quiet interval of 2 years and 9 months, an eruption broke out at Krafla on September 4, 1984. The eruption in November 1981 and associated deflation of magma reservoirs below Leirhnjúkur were followed by inflation, reaching previous levels in early 1982. Since then slow and intermittent inflation has continued, accompanied by earthquakes in the reservoir roof.

"Rapid deflation over the magma reservoirs, followed by volcanic tremor began September 4, at about 2025, but the eruption broke out at 2349. The beginning of the eruption was observed from the air by alerted scientists and a television reporter. The first fissure segment opened about 6 km N of Leirhnjúkur, followed within a minute by another about 3 km to the S. The fissures quickly joined and in 1 hour reached their full length of 8.5 km, extending from Leirhnjúkur to the N. During the first hours lava was erupted along the whole fissure, advancing on broad fronts.

"Already in the early hours of the morning, the activity had decreased and lava production on various sections of the fissures had faded out. By midday on September 5, inflation had resumed. By September 6,

News (cont. on p. 735)

Editorial

Dues

Perhaps even more important than the amount of dues that you pay to AGU is receiving what you paid for on time. The system for processing these payments at headquarters is out of date, and we are replacing it.

The member and subscription data were converted under rigid controls. We have taken pains to assure the completeness and the accuracy in the data conversion; however, there will be errors. We need you to assist in a final check on the data conversion.

In the next few weeks you will receive a mailing which uses labels from the new circulation system. Please watch for this mailing and make a note that you did in fact receive it. About a week later you will receive a second mailing which uses labels from the current circulation system. This second mailing will contain a form for you to return if you did not receive the initial mailing. If you receive only the second of these mailings, which will be clearly identified, please respond immediately by returning the form enclosed with the second mailing. This will allow us to correct your record promptly.

Your membership identification number will be changed. The new number will appear on all mailing labels produced by the new system. You can differentiate it from your current member code by the changed structure: the new code is a nine digit all numeric key. Your current code begins with the first four letters of your last name. We will make an announcement in *Eos* when the labels with the new codes are first used and give you other reminders of this change. If you keep a record of your current member code, watch for these notices and substitute the new code. All future communications with AGU headquarters about your dues and subscriptions will be handled more promptly if you use your new membership number. Please also remember to write it on any checks sent to AGU. If for any reason a check becomes separated from your order, we can more quickly resolve the problem with this number in hand.

For those who are interested, we have replaced the outdated batch processing software that has been run at a service bureau for the last 5 years with in-house dedicated hardware and specialized software for the circulation of journals. Scientific journal subscription records are maintained on similar systems at University of Chicago Press, MIT Press, John Wiley and Sons, and Springer-Verlag New York.

The new circulation system will provide far better statistical information. These reports will be valuable in planning and in the promotion of journals to nonsubscribing libraries.

Input is far less complicated than with our current system. The new software also has specific, sophisticated edits on the input, such as markers to catch duplicate payments, that are not available to us currently.

We are very enthusiastic about the capabilities of this new circulation system. It will significantly streamline our operation and improve our service to you. Your cooperation and help in the transition will make the system effective promptly.

Fred Spilhaus
Executive Director

The Oceanography Report

Texas, Helium, test tube, Water bottle, Scientific Machine, and Globe

The focal point for physical, chemical, geological, and biological oceanographers.

Editors: David A. Brooks, Department of Oceanography, Texas A&M University, College Station, TX 77843 (telephone: 409-845-5527).

Drifting Derelict Trajectories in the North Atlantic

Philip L. Richardson

Introduction

In December 1883 the U.S. Navy Hydrographic Office, a branch of the Bureau of Navigation of the Navy Department, began to publish monthly Pilot Charts. Earlier, oceanographer M. F. Maury had produced some summary survey charts showing ocean currents, winds, sailing routes, and the locations of whales. The new charts were unique in that they showed updated positions of derelict vessels and other drifting debris. From this series of positions of identified derelicts the first ocean trajectories were obtained. Much of this information has been forgotten during the last 100 years, and good collections of the Pilot Charts are rare. (The only complete collection that I could find is held by the Defense Mapping Agency.) This article is a recompilation and description of these early trajectories and a reminder of the usefulness of the Pilot Charts. It also provides a glimpse of a little known part of maritime history, the lost days of wooden sailing vessels.

The Pilot Chart

The new Pilot Charts were prepared to supply a reliable plotting sheet and a graphic presentation of recent as well as general summary information for mariners [*Hayden*, 1888]. The charts were issued free to navigators in return for their reporting recent navigational and weather information. The success of the Pilot Chart was due to the large number of observers that contributed information for each month's chart and its rapid distribution to ships. In the late 1800's there were nearly 3000 voluntary observers, mariners who crossed the North Atlantic and who patrolled its waters. Reports of marine meteorology and dangers to navigation were collected from these observers at 11 branch offices and forwarded to headquarters in Washington where the latest positions of wrecks and derelicts were plotted on a large blackboard. The Pilot Charts incorporated these data and were published and distributed at the beginning of each month. In November 1893 the office received no less than 400 reports daily from vessels in the North Atlantic alone. In New York during 1886–1887, 6,739 vessels were visited, 3,601 reports were forwarded to Washington, nautical information was furnished to 83,345 masters of vessels and others, and 10,397 Pilot Charts were distributed [*Hayden*, 1888].

Derelicts

A derelict is a vessel abandoned at sea. Derelicts that survived more than a few days at sea were usually wooden sailing vessels, and the longest surviving of these were often lumber schooners. From the point of view of a ship captain, a derelict vessel is a formidable obstruction to navigation. A collision with a derelict at night or in fog could damage or sink a ship. In our age of metal ships it is not generally recognized how many derelicts there were nor how long they remained afloat. The Atlantic was literally strewn with numerous "Mary Celestes" in various stages of disintegration.

The number of reported derelict sightings reached a maximum toward the end of the 19th century [*Hydrographic Office*, 1894]. During 1893, a year of particularly numerous derelicts, there were 752 reports of 418 different derelicts. One hundred six of these derelicts were identified by name. All but two or three of these derelicts were wooden. Over a 7 year period, 1887–1893, a total of 1,628 derelicts were sighted, an average of 232 annually, 19 per month. This suggests that at any one time at least 19 derelicts remained afloat in the North Atlantic. The average length of time a derelict remained afloat is estimated to be 30 days. This time is based on assuming a derelict remained afloat 1 day after its last reported sighting or 3 days for a single sighting. During 1887–1893 there were 1,944 reports of the 482 identified derelicts giving an average of four sightings per derelict. The greatest number of derelicts were first reported in September-November and were caused by severe storms. Most were located in the Gulf Stream off the U.S. coast. The numbers of sightings gradually decreased eastward along the transatlantic steamer routes. Many of the large number of derelicts observed during the fall of 1893 were caused by a series of three hurricanes which occurred in August of that year.

Derelict Trajectories

Numerous derelicts remained afloat over half a year and were reported often enough to give long and interesting ocean trajectories. A listing of derelicts that floated longer than 200 days is given by *Richardson* [1984]. Six of the derelicts drifted longer than a year: (1) schooner *Fannie E. Wolston*, 1100 days; (2) schooner *Wyer G. Sargent*, 615 days; (3) bark *Telemach*, 551 days; (4) bark *Vincenzo Perrotta*, 536 days; (5) schooner *Ethel M. Davis*, 370 days; and (6) schooner *James B. Drury*, 367 days.

The trajectories of three long-lasting and far-drifting derelicts are shown in Figure 1. One of the best known of these was the three-masted lumber schooner *W. L. White*, belonging to A. F. Ames of Rockland, Maine. She was abandoned off Delaware Bay during the great blizzard of March 13, 1888. A telegram dated Stornoway, Hebrides Islands, Scotland, January 23, 1889, marked the termination of the *White*'s 310 day transatlantic drift. She ended stranded upon Haskeir Island in the Hebrides.

The *White* began her drift southward under the influence of the inshore current and northwest gale, with masts and portions of her sails standing. Upon reaching the Gulf Stream she turned and followed a east-northeast course at an average speed of about 32 miles per day. From May to November 1888 she looped and zigzagged east of Newfoundland directly within a major shipping lane. During these 6 months she was reported by 36 vessels, three of which sighted her in a single day. In her cruise of 10 months and 10 days, she traversed a distance of 5,900 miles and was reported 45 times.

Although the detailed paths of the derelicts are very different from each other, there are some similarities which might be described as patterns. Eight of the longest drifting derelicts moved eastward in the Gulf Stream until they reached 50°W where their paths diverged. Three derelicts continued eastward and crossed the Atlantic in an average time of 10 months. The *White* took 310 days, the *Twenty-one Friends* took 255 days, and the *Hunt* took 347 days. Six derelicts drifted southward from the Gulf Stream near 40°W. The *Drury* and the *Hill* both made tight turns and drifted westward just south of the Gulf Stream. The *Wolston* made a complete circuit of the gyre during its 3-year drift. This derelict drifted south to 25°N, westward to the Bahamas, and then northeastward into the Gulf Stream again, crossing its earlier path. The trajectory of the *Telemach*, which was 1.5 years long, is similar to part of the *Wolston*'s. Two derelicts drifted erratically but in a general southwestward direction through the Sargasso Sea and grounded on the Bahama Islands.

Most derelicts looped as they drifted. The *Sargent* and *Wolston* made large, 500 km loops with a characteristic period of 10 months near 30°N, 40°W. Several other derelicts made frequent smaller scale loops: the *Perrotta* and *Francis* in the Sargasso Sea and the *White* east of Newfoundland.

An example of variability of ocean surface currents is given by the drift of the bow and stern of the *Fred B. Taylor*. On June 22, 1892, the *Trave* collided with the *Taylor* and the latter was cut in two (from Pilot Chart, September 1892). The forward and after parts separated and drifted in entirely different directions (Figure 2). The bow went 340 miles during 93 days and was reported 47 times. The stern went 350 miles during 47 days and was reported 20 times. The different directions could have been partly caused by the different areas of bow and stern presented to the wind and current.

Superimposed Trajectories

A summary diagram was prepared that shows 200 derelict trajectories reported in the Pilot Charts from 1885 to 1902 (see cover). Earlier but less complete charts showing trajectories of derelicts have been given in the supplements of February 1889 and 1893 to the Pilot Charts, by the *Hydrographic Office* [1894], and by *Hautreux* [1897]. Derelict vessels which first appeared near the U.S. Coast south of Long Island and north of Cape Hatteras usually drifted in a southward direction following the inshore current until they reached Hatteras, where they entered the Gulf Stream and drifted eastward.

In general, derelicts entered the Gulf Stream north of 30°N and moved eastward in the Stream. When they reached the area south of the Grand Banks, near 40°N, 50°W, they split into two bands of trajectories. The first band reaches northeastward and then eastward, passing north of the Azores between 40° and 50°N. The second band extends southeastward and then westward near 25°N. Six derelicts moved southward between the Azores Islands and Spain and Portugal. The general pattern indicated by the collected trajectories is of a large clockwise gyre split into two branches, one branch located north of the Azores, the other southwest of the Azores. The splitting of the Gulf Stream near the Grand Banks has been confirmed by more recent measurements [*Mann*, 1967; *Clarke et al.*, 1980], but it is still controversial [*Worthington*, 1976].

Superimposed on the large-scale, long-term general circulation pattern can be seen considerable current variability. The derelicts do not often smoothly follow the large-scale gyre; instead they drift in convoluted trajectories that often cross each other. The convoluted paths give an early Lagrangian measure of mesoscale eddies and longer period current fluctuations. We now know that the ocean is populated by energetic eddies that are usually much stronger than the mean currents [*Schmitz et al.*, 1983; *Robinson*, 1983]. Recently, the importance of these eddies to the general circulation has been recognized, and they have been studied intensively. Because of these eddies, the mean circulation becomes recognizable only by averaging a great quantity of observations in space and time, as can be done by eye on the cover. In the Gulf Stream, the North Atlantic Current, and the North Equatorial Current, one clearly sees the general drift in spite of the eddies. In the Sargasso Sea the trajectories are dominated by mesoscale eddy motion.

One should be cautious about interpreting all the motion indicated by trajectories as being due to water movement. Derelict ships varied in size and weight and in state of damage when abandoned. Some were totally dismasted and filled to the gunwales with water. Along with the 30% of the sightings which were of vessels that had turned bottom up, these probably provided a good indication of the speed and trajectory of near surface water. Derelicts with masts standing and those riding high in the water would no doubt be significantly influenced by the winds blowing directly on the mast and exposed hull.

There are the additional problems of position errors of the reporting ship, misidentification of derelicts, and infrequent sightings. It is difficult to evaluate with the available information how accurate the details of trajectories really are. The average number of days between sightings is about 20, which is sufficiently small that we can see some aspects of mesoscale eddies but not small enough except in a few occasions to resolve individual loops. Despite the lack of frequent and precise positions, the collection of the trajectories represents a realistic view of the general Lagrangian circulation and of current variability.

Within the last decade, freely drifting buoys remotely tracked by satellite have begun to be used in large numbers to measure velocities and trajectories of near-surface currents. The newer measurements have the advantage over earlier derelict trajectories of several fixes per day and a higher positional accuracy. From a collection of these measurements we have been able to obtain a more quantitative picture of aspects of the general circulation and of the geography of ocean variability. A summary figure of the buoy trajectories [*Richardson*, 1983] shows general patterns very similar to those of the derelict trajectories. If these buoys continue to be deployed in the North Atlantic we might expect that the numbers of their trajectories may eventually surpass the numbers of drifting derelict trajectories.

Derelict sightings and trajectories have been viewed here as giving interesting information about ocean currents. We should not forget that this information came with a tragic loss of life and shipping. Toward the end of the 19th century, 12,000 lives and 2,200 vessels were lost at sea each year worldwide (supplement to February 1893 Pilot Chart). Each severe storm that was encountered at sea left new derelicts in its path and added new names to the long list of vessels and men who left port but were never heard of again. The plots of derelict sightings are a sad reminder of lost vessels, suffering, and death.

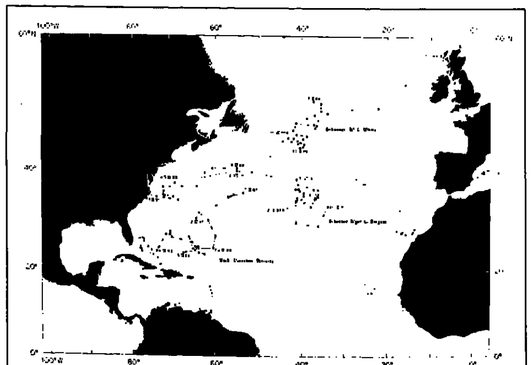

Fig. 1. Trajectories of (1) the schooner *W. L. White* from March 13, 1888, to January 23, 1889, a drift of 5,190 miles and 310 days; (2) the schooner *Wyer C. Sargent* from March 3, 1891, to December 6, 1892, a drift of 5,500 miles and 615 days; and (3) the bark *Vincenzo Perrotta* from September 17, 1887, to April 4, 1889, a drift of 2,950 miles and 536 days.

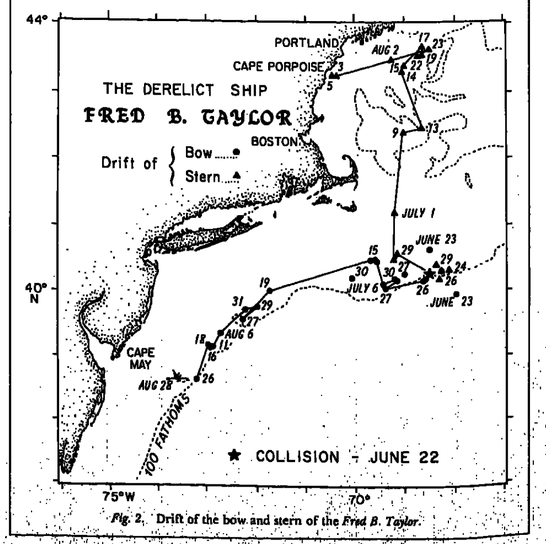

Fig. 2. Drift of the bow and stern of the *Fred B. Taylor*.

EOS

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Cover. Superposition of drifting derelict trajectories plus a few drifting buoys during 1885–1902 as given by the monthly Pilot Charts, first published by the U.S. Navy Hydrographic Office, a branch of the Navy Department, in 1883. A few derelict trajectories close to the U.S. east coast were omitted for clarity. The general pattern shows the large-scale ocean circulation. Convolutions of trajectories and those that cross each other show the time variability of ocean currents. (Figure courtesy of Philip L. Richardson, Woods Hole Oceanographic Institution, Woods Hole, Mass. See article "Drifting Derelict Trajectories in the North Atlantic," by Philip L. Richardson, this issue, The Oceanography Report, p. 730.)

Acknowledgments

A. Green kindly made available the Defense Mapping Agency's collection of Pilot Charts, 1883–1902. Funds were provided by the National Science Foundation under grant OCE81-09145. This is an abbreviated version of a paper that discusses the same information [*Richardson*, 1984].

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Mathematical Models for Zooplankton Swarms: Their Formation and Maintenance

Akira Okubo and James J. Anderson

Introduction

Many aquatic invertebrates are known to form swarms and schools. Thus, zooplankton are usually distributed unevenly both in vertical and in horizontal directions. There are a great number of studies on zooplankton swarms ranging from simple records or observations to more extensive functional and behavioral investigations. Yet, no attempt has been made on mathematically modeling these phenomena, chiefly because of the lack of detailed data on individual movements in swarms.

Swarms are groups of individuals engaging in more or less cohesive movements without parallel orientation. The presence or absence of parallel orientation distinguishes schools from swarms. Individual organisms in a swarm apparently exhibit irregular movements which might be regarded as random. However, random motion alone makes a group of organism spread out to occupy a larger space as time progresses (i.e., diffusion). Therefore, an adequate model for zooplankton swarming must assume certain regularities in the motion of individuals superposed upon its randomness. This deterministic part arises primarily from behavioral interactions between swarming individuals and possesses the nature of an attractive force. A swarm is maintained by the balance between the deterministic and stochastic forces. Modeling for swarm formation involves random search for prey or conspecific individuals followed by accelerated aggregation as a result of mutual communication or biological cue.

In this report we will present both kinematical and dynamical models for the maintenance and formation of swarms.

Kinematic Interpretation of Difference Between Swarming and Diffusion

We consider a simple one-dimensional case (*x* axis). Swarming implies randomness in motion. Thus both velocity $v(t)$ and displacement $x(t)$ of an individual in a swarm are random variables.

As a statistical measure determining the swarm dimension, the variance of the displacement is calculated by averaging the square of x over the ensemble (e.g., over a sufficiently large number of individuals in a swarm). Without loss of generality we assume that the individual organisms to start at $x = 0$ and the individual movement to be symmetrical with respect to the origin so that the swarm centroid remains at the origin. Thus, the variance of x is obtained by

$$\overline{x^2}(t) = \int_0^t \int_0^t \overline{v(t')v(t'')}\,dt'\,dt'' = 2\int_0^t \overline{v^2}(t-\tau)R_L(\tau)\,d\tau = 2\overline{v^2}\int_0^t \tau R_L(\tau)\,d\tau \qquad (1)$$

where

$$R_L(\tau) = \overline{v(t')v(t'+\tau)}/\overline{v^2} \qquad (2)$$

is the Lagrangian velocity autocorrelation coefficient. We have assumed that the random velocity field is stationary so that the correlation coefficient depends only on the time lag τ.

Equation (1) provides us with kinematic distinction between diffusion and swarming in terms of the velocity autocorrelation. By diffusion we mean that the individual velocity loses its statistical dependence on past velocities as the dispersion continues. In other words, $R_L(\tau)$ approaches zero at large time lags such that the both integrals in (1) converge as $t \to \infty$. We then find from (1) that as $t \to \infty$,

$$\overline{x^2}(t) \to 2Dt \qquad (3)$$

where

$$D = \overline{v^2}\int_0^\infty R_L(\tau)\,d\tau \qquad (4)$$

If, on the other hand, (1) is to mathematically describe swarming, $\overline{x^2}$ must approach a constant value for steady state swarm maintenance. This is satisfied only if $R_L(\tau)$ oscillates about zero value in such a manner that $d^2R_L(\tau)/d\tau$ approaches zero asymptotically, and, consequently, the second integral of (1) approaches a negative constant value. In physical terms, the individual motions appear to resemble a random pendulum-like motion about $x = 0$. Experimental confirmation on this model would be to determine the velocity autocorrelation coefficient of individual animals in a swarm.

Dynamical Model for the Maintenance of Swarm

We now consider a dynamical model for swarm maintenance. Newton's equation of motion will be applied to swarming animal motion. We assume that (1) the frictional force is proportional to the velocity of organism (in fact, Reynolds numbers associated with zooplankters range from 0.1 to 500 [*Zaret*, 1980] so that the Stokes' law of drag may not be applicable to some large and fast moving zooplankton); (2) the nonrandom force is attractive by nature toward the center of swarm and dependent on the distance from the center; and (3) the random force is a type of white noise.

Then the equation of motion is given by

$$\frac{d^2x}{dt^2} = -k\frac{dx}{dt} - \omega^2 x - \phi(x) + A(t) \qquad (5)$$

where k is the frictional coefficient, ω is the frequency of harmonic component of the attractive force, $\phi(x)$ is the acceleration due to anharmonic component of the attractive force, and $A(t)$ is the random acceleration of a white noise nature;

$$\overline{A} = 0 \qquad \overline{A(t)A(t+\tau)} = 2B\delta(\tau) \qquad (6)$$

where B is the intensity of the variance of $A(t)$.

An approximate analytical solution of (5) may be obtained by the method of equivalent linearization [*Bulsara et al.*, 1982]. To this end, (5) is replaced by a linear system with an equivalent linear frequency ω_e such that

$$\omega_e^2 = \omega^2 + \overline{(x\phi(x))}/\overline{(x^2)} \qquad (7)$$

where the angle brackets denote a time average over one cycle of oscillation of $x = a\sin\omega t$.

Solving this linearized version of (5) for x, we calculate the velocity-autocorrelation coefficient to be

$$R_L(\tau) = e^{-k\tau/2}(\cos\omega_1\tau - k/2\omega_1 \sin\omega_1\tau) \qquad (8)$$

where

$$\omega_1^2 = \omega_e^2 - k^2/4$$

Also the variance is found to be

$$\overline{x^2} = B/k\omega_e^2 \qquad (9)$$

as $t \to \infty$.

This dynamical model enables us to obtain the variance of displacements of swarming animal in terms of parameters that characterize the motion of individuals. The square root of (10) scales the spatial extent of swarm. With certain modifications on the stochastic forcing function $A(t)$ the dynamical model equation (5) or its equivalent linearization is also applicable to schooling of fish [*Okubo*, 1980].

In view of the assumed nature of the stochastic force the random process (x, v) is Markovian, and the probability density function (p.d.f.) $p_2(x, v, t)$ obeys a Fokker-Planck equation. We thus obtain from (5) and (6)

$$\frac{\partial p_2}{\partial t} = -v\frac{\partial p_2}{\partial x} - \frac{\partial}{\partial v}\{(-kv - \omega^2 x - \phi(x))p_2\} + B\frac{\partial^2 p_2}{\partial v^2} \qquad (11)$$

Since p_2 is an even function of x and the nonrandom attractive force is an odd function of x, integral of (11) over x leads to

$$\frac{\partial p_1}{\partial t} = k\frac{\partial}{\partial v}(v\,p_1) + B\frac{\partial^2 p_1}{\partial v^2} \qquad (12)$$

where

$$p_1(v, t) = \int_{-\infty}^{\infty} p_2(x, v, t)\,dx: \text{ p.d.f. of velocity} \qquad (13)$$

For steady state p_1^*

$$p_1^*(v) = (k/2\pi B)^{1/2} e^{-k/2B\,v^2} \qquad (14)$$

which is the Maxwellian velocity distribution.

The p.d.f. of displacement x may be obtained by integrating $p_2(x, v, t)$ over v

$$p_e(x, t) = \int_{-\infty}^{\infty} p_2(x, v, t)\,dv \qquad (15)$$

Alternatively, if we use the Smoluchowski-Kramer approximation or the method of adiabatic elimination [*Gardiner*, 1983] in (5), we obtain

$$\frac{\partial p_1}{\partial t} = \frac{\partial}{\partial x}\left(\frac{\omega^2 x + \phi(x)}{k}p_1\right) + \frac{B}{k}\frac{\partial^2 p_1}{\partial x^2} \qquad (16)$$

The steady state p.d.f. p_1^* gives the number density distribution of swarming organisms

$$p^*(x) = p_0 \exp\left\{-\frac{\omega^2}{2B}x^2 - \int\frac{\phi(x)}{B}dx\right\} \qquad (17)$$

where p_0 is the density at the swarm center. The non-Gaussian density distribution arises from the anharmonic attractive force. Since $x\phi(x) > 0$, the density distribution tends to be platykurtic. It is conceivable that the anharmonic attractive force is a manifestation of density-dependent advective velocity toward the swarm center. It is a built-in mechanism to maintain a sharp boundary of concentration despite a general tendency to spread by the random component of motion. The net effect also produces a more or less uniform density of organisms within a swarm which is characteristic of a platykurtic distribution.

Comparison With Data

Verification of our mathematical models for swarming requires comparisons with appropriate data; to our regret no such data really exist in the marine field. In desperation we are forced to borrow data from "nonplankton" (i.e., insect) swarming.

High-speed filming on swarming of midges, *Anarete pritchardi* Kim, provides us with basic kinematic data for evaluating swarm maintenance characteristics such as velocity autocorrelation coefficient, velocity frequency distribution, acceleration field, swarm dimensions, and insect number density distribution [*Okubo and Chiang*, 1974; *Okubo et al.*, 1977].

Figure 1 shows the velocity- and acceleration-vector field of individual midges in an instance of swarming. The midge of size 1–2 mm moves with high accelerations, occasionally twice or more the acceleration of gravity (G). The motion inside the swarm looks more or less random in both velocity and acceleration, but the midge is subject to an inward force (or rather acceleration) which is felt strongly at the swarm edge. As we model in (5), the presence of this inward-oriented force plays a crucial role in maintaining the

Oceanography (cont. on p. 732)

Oceanography *(cont. from p. 731)*

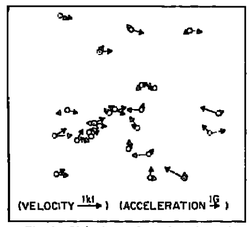

Fig. 1. Velocity and acceleration field of individual animals in an instance of swarming.

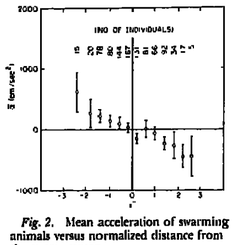

Fig. 2. Mean acceleration of swarming animals versus normalized distance from the swarm center.

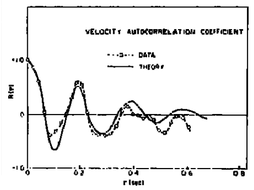

Fig. 3. Velocity autocorrelation coefficient of swarming animals versus time lag.

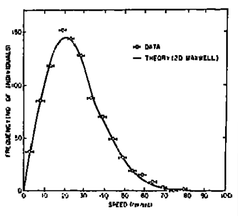

Fig. 4. Speed frequency distribution of swarming animals.

swarm against a general tendency of spread by the randomness in the motion. The acceleration field in swarming can be seen more clearly in Figure 2, where we plot the mean acceleration of swarming animals against normalized distance from the swarm center.

Figure 3 shows the velocity autocorrelation coefficient against time lag. The theoretical curve is based on (8) with $k = 6.8/s$ and $\omega_e = 31.6/s$. The observed behavior of the autocorrelation coefficient is consistent not only with the kinematic interpretation of swarming but also with the dynamical model.

Figure 4 shows the frequency distribution of insect speed in a swarm, which can be well approximated by the Maxwell speed distribution. The theoretical curve is based on (14) with $k = 6.8/s$, $B = 1.22 \times 10^4$ cm^2/s^3; the value of B is estimated from the observed mean squared velocities of individuals.

The number density distribution of swarming individuals is in fact platykurtic as our mathematical model, equation (17) predicts. For six swarms of *Anarete* the mean kurtosis is 2.60, and the difference from normality (Kurtosis = 3) is statistically significant. As explained earlier, this deviation from normality arises from anharmonic attractive forces that correspond to density-dependent advective velocity toward the swarm center. *Okubo and Chiang* [1974] obtained empirically with *Anarete* swarms that the advective velocity scaled by diffusivity is proportional to the minus ½ power of the number density.

Dynamical Model for the Formation of Swarm

Modeling swarm formation is much more difficult than that of swarms maintenance simply because we deal essentially with a transient behavior. The dynamical model of swarm formation assumes two processes (i.e., initial random encounter of conspecific individuals and accelerated aggregation followed).

The initial phase of swarm formation may be modeled in a way similar to *Anderson* [1981]. Namely, the change with time of the number of individuals $N(t)$ in a swarm is determined as the difference between the rate that zooplankton enter the swarm, which is independent of N without communication, and the rate that zooplankton exit from the swarm, which is proportional to N. We thus have

$$\frac{dN}{dt} = a - bN \qquad (18)$$

where a and b are constants. Possible stochasticity in a and b may be incorporated [*Anderson*, 1981]. The solution of (18) subject to $N = 1$ (one individual) at $t = 0$ describes an asymptotic approach to a stable equilibrium $N_e = a/b$ with a rate of b^{-1}.

This equilibrium state would not be realized, however, if mutual communication exists as swarming progresses. Some possible mechanisms by which zooplankton might communicate are light, pressure changes due to sound generation, and chemosensory by means of pheromones. Aggregation behavior in response to pheromones has been well known in insects, and chemical communication has been observed in copepods and planktonic shrimp.

If chemosensory is assumed as the mechanism of zooplankton communication, we can construct a simple model for the accelerated aggregation process that leads to a massive swarm or "superswarm."

First consider diffusion of a chemical from a spherical source of radius R. For steady state the concentration of chemical C is given by

$$C(r) = Q/4\pi Kr \qquad r \geq R \qquad (19)$$

where Q is the rate of release of chemical, K is diffusivity, and r is the distance from the center of the sphere.

We now regard the source as a swarm, in which $N(t)$ is the total number of individuals, ρ is the mean volume occupied by one individual, and q is the emission rate of chemical by one individual;

$$C(r, t) = qpN(t)/4\pi Kr \qquad (20)$$

Let C^* be the threshold concentration for chemosensory response. Then the effective sphere of chemical communication around the swarm has the volume of

$$V = \frac{4}{3}\pi r^{*3} - \frac{4}{3}\pi R^3$$

$$\approx \frac{4\pi}{3}\left(\frac{qp}{4\pi KC^*}\right)^3 N^3 - \rho N \qquad (21)$$

Any individual who happens to be within the sphere of influence will be attracted to the swarm by chemotaxis. Let v be the velocity of chemotaxis and S_o be the background density of zooplankton. Then the change with time of the number of individuals in the swarm is given by

$$\frac{dN}{dt} = v s_o V = v s_o \mu(N^3 - \lambda N) \qquad (22)$$

where

$$\mu = \frac{4\pi}{3}\left(\frac{qp}{4\pi KC^*}\right)^3$$

and

$$\lambda = \frac{3}{4\pi}\frac{(4\pi KC^*)^3}{q\,p^2}$$

The solution of (22) subject to $N = N_o$ at $t = t_o$ is obtained by

$$N(t) = \left[\frac{\lambda}{1 - (1 - \lambda N_o^{-2})\exp\{2\nu s_o \mu(t - t_o)\}}\right]^{1/2} \qquad (23)$$

This solution describes the avalanche of aggregation in such a manner that the swarm reaches an infinite size within a finite time span given by

$$t - t_o = (2\nu s_o \mu)^{-1}\, \ell n\,(1 - \lambda N_o^{-2})^{-1} \qquad (24)$$

which for small λN_o^{-2} approximates

$$t - t_o = (2\nu s_o\, \mu N_o^2)^{-1} \qquad (25)$$

The knowledge of the pertinent parameters would enable us to estimate this critical time. Again, no such data exist in marine swarming. The presented model may also be applicable to acoustic communications with minor modifications.

Discussion

We have outlined mathematical models for the formation and maintenance of zooplankton swarms. The theories extend beyond the ability of observation in many instances, and this may be criticized since some consider that theory without observations is a scientific crime. In fact we believe it is a crime not to. In justification of this view we reference the synergistic relationship between theory and observation in particle physics. In many ways, zooplankton are not unlike particles but with very elaborate laws of governing their behavior.

Our approach at this time is to consider the very basic features of swarming and to compare our mathematical models with available data on insect swarming. To proceed into marine swarming, kinematic data on zooplankton swarming are urgently needed for evaluation of the mathematical models. For example, information on the basic swarm properties: the density of swarms in a habitat and the density of zooplankton in a swarm will enable us to estimate at least the ratio of the diffusivity and the attractive forces in terms of the number of density [*Okubo and Chiang*, 1974].

In perspective, this paper is written by two persons who eagerly undertake to build models of zooplankton swarming in the dim hope that they will find a scent of a "working hypothesis" on swarming that can be tracked by biologists. It remains to be determined if the creature whose track we follow will be categorized as "BIOSENSIS" or "BIONONSENSIS."

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Information Report

Biowatt: A Study of Bioluminescence and Optical Variability in the Sea

On entering water, light is both scattered and absorbed. The sum of these is attenuation. In the open ocean, the agent of most scattering and absorption is plankton, or plankton-derived products. The controls, therefore, governing the variability in light absorption and scattering are no less than the controls governing the distribution, abundance, and growth of plankton populations. Apart from being attenuated, light is also generated ubiquitously in the upper layers of the sea through mechanisms of bioluminescence. The overall and long-term goal of Biowatt is to establish causal links operating between the variability in light attenuation and light production in the ocean. The issues addressed range from behavioral relationships among macrozooplankton and microneckton, to the dynamics of absorbing and scattering populations, to the physical dynamics of the upper layers. A conceptual model is shown in Figure 1.

The beginnings of Biowatt can be traced to an advisory meeting convened by the Office of Naval Research (ONR), in December 1982 at Berkeley, Calif. The 30-odd meeting attendees explored various research and instrumentation development avenues within the framework of bioluminescence and optical variability in the ocean. Preliminary recommendations from the group covered immediate tasks, overall design of the program, possible field sites, and the sort of modeling effort which should accompany and guide the observations [*Blizard et al.*, 1982]. During 1983, the program continued to evolve in concept, drawing much scientific support and insight from a predecessor ONR program, the Optical Dynamics Experiment (ODEX). Funding approval from ONR for Biowatt came in early 1984, at which time a steering committee was selected. (The Biowatt Steering Committee members are James F. Case (UCSB), Tom Dickey (USC), John Marra (LDGO), Mary Jane Perry (UW), Raymond C. Smith (UCSB), and Elijah Swift (URI).) The program is expected to have a duration of 5 years, with field years in 1985 and 1987. We now turn to some of the specific issues Biowatt will address in the coming field experiments.

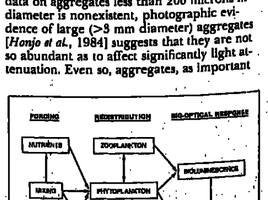

Fig. 1. A conceptual model for Biowatt.

Optical Variability in the Ocean

Biological and optical oceanographers traditionally deal with plankton populations in terms of such macroscopic, but easily measured, variables as chlorophyll *a*, particle counts and beam transmittance. In many kinds of biological oceanographic studies, such as the influence of physical processes on phytoplankton, these are the variables of choice since the sampling design necessitates near continuous data acquisition. However, studies of the dynamics of plankton communities require much more elaboration of organism type and function, and trophic processes, but with a compromise of sampling coverage. An understanding of the optical variability of the ocean will require both kinds of research: the physical forcings upon macroscopic variables as well as the detailed character of the biological distributions and dynamics that these forcings permit.

For example, at one level, we need to understand how physical processes in the upper ocean influence vertical distributions of chlorophyll *a* and particulate matter, and thereby the behavior of inherent and apparent optical properties. (These optical properties refer, respectively, to those independent of and dependent on, light source distribution.) A variety of physical processes contribute to the mass, momentum, and energy budgets in the upper ocean, however, a few phenomena can be identified as major sources of the variance spectra of physical and biological data fields. According to *Klein* [1980] and *Dickey and Simpson* [1983], wind and surface current interactions caused by inertial resonance phenomena may explain rapid mixed-layer deepening, which, if true, means that nutrient fluxes may vary substantially on time scales of hours [*Klein and Coste*, 1984].

Beyond this, developing predictive relationships between biological particles and optical properties in the ocean requires much more exhaustive specification of the nature of absorbers and scatterers. From an optical perspective, biogenic particles are ensembles of sizes, shapes, pigments, and refractive indices. We do not understand enough about the nature of the particles themselves and their distributions (let alone their dynamics) to enable an understanding of their influences to variability in absorbance and scattering.

Although the various types of phytoplankton (diatoms, dinoflagellates, cyanobacteria, etc.) together can theoretically absorb light over the entire underwater spectrum, the spatio-temporal distribution of absorbing pigments other than chlorophyll *a* is poorly known. Further, the density distribution of pigments within individual cells will directly affect the absorption coefficient. The identity of particles which dominate scattering is also poorly known, largely because we understand very little concerning the composition, trophic structure, and interrelationships of plankton communities of the open ocean. One of the more significant finds of the last several years is the food web, grazers, producers, and remineralizers, composed of organisms less than 10 microns in diameter. The dynamics of this food web is largely unexplored, but it is possible that much of the flux of matter and energy in the open ocean occurs in this size range of organisms.

Related to this is the problem of detrital and organism aggregates, sometimes called "marine snow." Much of our current knowledge of the occurrence and nature of marine snow is anecdotal. Recent work suggests its importance to production and food web dynamics [e.g., *Knauer et al.*, 1982; *Caron et al.*, 1982; *Goldman*, 1984]; however, quantitative and nondestructive sampling of aggregates is extremely difficult. While abundant data on aggregates less than 200 microns in diameter is nonexistent, photographic evidence of large (>3 mm diameter) aggregates [*Honjo et al.*, 1984] suggests that they are not so abundant as to affect significantly light attenuation. Even so, aggregates, as important absorbers and scatterers, may be missed, since current optical instruments measure a small volume and there is presently no means of extrapolating to bulk optical properties over the water column. Furthermore, it is possible that aggregates strongly influence food web dynamics. So even if their direct effect optically is small, their indirect effect could be large.

Bioluminescence in the Ocean

A major goal of Biowatt is to predict patterns of oceanic bioluminescence and relate these to variability in optical properties over appropriate spatial and temporal scales. For purposes of modeling bioluminescence potential in the sea, an immediately obvious generalization is that the numbers and types of bioluminescent members of a pelagic community define the limits of the bioluminescent potential. That is to say, it should be possible to predict the bioluminescence potential from knowledge of the distributions of bioluminescent organisms.

Predictions of actual bioluminescence are complicated by considering that (1) light is generated in the ocean by six (of the seven known) bioluminescence systems; (2) in some marine environments, over 97% of the individual organisms and 90% of the species have been reported to be bioluminescent [*Young*, 1983]; (3) spectral emission ranges in color from the near UV to the far red; (4) kinetics range from 60 ms flashes to continuous glows lasting several minutes; and that (5) intensity of the emission is controlled by a variety of biological mechanisms. Furthermore, the actual bioluminescent signal which can be elicited by strong mechanical stimulation is modulated by the physiological state of the organisms, reproductive and nutritional status, etc., as well as a variety of environmental factors.

Undoubtedly, the least understood and perhaps the most intractable aspects of Biowatt are the biological determinants of bioluminescent response. Nevertheless, significant progress has been made in oceanographic bioluminescence research. For example, instead of dinoflagellates and fish, zooplankton have been found to be the most important bioluminescent source in the Sargasso Sea (Table 1) and perhaps in many areas in the open ocean. Recent observations point to clear relationships between temperature fronts, chlorophyll *a* distributions, and stimulable bioluminescence (Figure 2). Other observations (E. Swift et al., manuscript in preparation, 1984) show variable depth coherence between the deep chlorophyll maxima and bioluminescence potential. In the Sargasso Sea, the bioluminescence potential peak has been observed to be as much as 40 m above the chlorophyll maximum, while in some of the island passages in the Caribbean the peaks are coincident.

Spatio-temporal scales of bioluminescence are largely biologically determined. In some areas, such as the Norwegian Sea, bioluminescence is strongly sensonal because of the population dynamics of crustacean zooplankton. In the Sargasso Sea, on the other hand, there appears to be relatively little seasonality in numbers of relative abundance of bioluminescent organisms (E. Swift et al., manuscript in preparation). Biogeographic communities have been defined in which the relative numbers of bioluminescent and nonbioluminescent members have a stable relationship [*McGowan*, 1978]. It is possible that population and biological studies of species responsible for much of the bioluminescence potential will be particularly useful in predicting patterns of bioluminescence.

Field Studies

The first Biowatt experiment will be a cruise, now scheduled for April 1985. The general plan for this initial phase of Biowatt will be to sample different water masses in the northwest Atlantic for biological and optical properties and for bioluminescence potential. The questions we ask during this phase of the program are ones of composition, identification, size distributions, and pigment distributions of the biological populations. We are particularly interested in the vertical structure of physical and optical properties, biological variables, and bioluminescence potential and their interrelationships.

The overall success of the program is highly dependent on the resolution of relevant temporal and spatial scales of variability in physical, biological, and optical parameters. From a biological standpoint, the two most important time scales are the diurnal and the seasonal. The diurnal time scale is accessible from shipboard platforms; however, seasonal time series for open ocean locations are rare. We believe a surface mooring to be the best means of characterizing the temporal evolution of physical, biological, bioluminescence, and optical parameters at a given location, and this is planned for the subsequent field effort in 1987. The mooring will provide an opportunity to sample for a long enough period to evaluate seasonal cycles, with enough sampling density to assess aperiodic variability associated with synoptic weather systems. The mooring will be equipped with a wide variety of the latest physical, biological, bioluminescence and optical sensors. During cruises to service the mooring, shipboard programs can be accomodated to sample short-term variability not accessible from the in situ observations, to allow various kinds of experimental programs to help interpret mooring observations, and to characterize spatial variability and horizontal gradients in the vicinity of the mooring.

Again, the overall and long term goal of this study is to be able to make predictions of the optical properties and bioluminescence patterns of the sea from a knowledge of physical forcings, biological processes, and the interrelationships between physical, biological, and optical properties. A key link in this effort is the distribution and variance of biogenous absorbers and scatterers, their size and pigment distributions, and the dynamics of these biological populations. Clearly, this will require concerted efforts by physical, biological, and optical oceanographers.

Investigators interested in Biowatt are invited to contact the Biowatt Project Office, care of Lamont-Doherty Geological Observatory, Palisades, New York 10964.

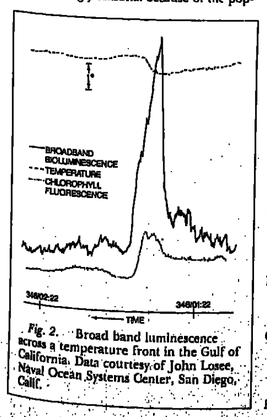

Fig. 2. Broad band luminescence across a temperature front in the Gulf of California. Data courtesy of John Losee, Naval Ocean Systems Center, San Diego, Calif.

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This information report was contributed by John Marra *of the Biological Oceanography Group at Lamont-Doherty Geological Observatory of Columbia University, Palisades, NY 10964 and* Eric O. Hartwig *of the Office of Naval Research, Arlington, VA 22217.*

TABLE 1. Bioluminescent Taxa Responsible for Epipelagic Bioluminescence in the Sargasso Sea (0–100 m) Giving Concentrations Per Cubic Meter. C, Bioluminescence Potential, BP, and Relative Importance, I

Group	C	BP	B	I
Dinoflagellates				
Pyrocystis	30			
Other	30	2×10^{10}	6×10^{11}	1/10
Copepods		10^9	3×10^{10}	
Pleuromamma	2			
Others	30?	2×10^{12}	4×10^{12}	6/10
Ostracods	10	?		
Euphausids		1×10^{11}	10^{12}	1–2/10
Adult	0.2			
Larvae	8	1×10^{12}	2×10^{11}	1/10
Decapods		4×10^{10}	3×10^{11}	
Sergestids	0.002			
Others	0.00001	10^{13}	10^{10}	
Mysids	?	10^{157}	10^{107}	
Amphipods	?	?	?	
Larvaceans	20	10^{11}	?	
Coelenterates	5	4×10^{107}	8×10^{11}	1/10
Polychaetes	0.3	2×10^{10}	10^{11}	
		6×10	10^{10}	

Data courtesy of Elijah Swift, Graduate School of Oceanography, URI, Kingston, RI 02881.

Applications. Seasat had recently failed after only 96 days, and its successes or failures were as yet unknown. By implementing a plan for the utilization of these first-ever satellite data intended for ocean research, he and NASA have demonstrated the tremendous promise of oceanography from space.

His branch is now planning a series of new satellite missions for oceanography. These are a NASA scatterometer (for wind measurements) to fly on the Navy Remote Ocean Sensing System (NROSS) in 1989, an improved radar altimeter to measure ocean circulation for the Ocean Topography Experiment (TOPEX) in 1989, and Ocean Color Imager (OCI) for biological research. These missions have been designed through the close coordination of the NASA engineering and ocean sciences communities, as well as the Office of the Oceanographer of the Navy, the National Science Foundation, ONR, and NOAA. Stan has recognized the importance of the cooperation between different scientific disciplines. With skill, dedication, and patience he has advocated ideas through interagency planning. Working in concert with the scientific research, engineering, and operational oceanography communities, oceanography now has the potential for longer-term, larger-scale studies of the global oceans.

In summary, Stan's exposure to the many facets of oceanography while at ONR has served the ocean sciences well at NASA. His high energy, coupled with scientific foresight, has introduced the new satellite technologies to ocean research. He has had the tenacity and courage to break this new ground, as well as the statesmanship to convince the traditionalists in the oceanographic community of the potential value of satellite ocean remote sensing. Oceanographers are now looking to future programs that will incorporate satellite measurements as a crucial element. For his central role in the establishment of satellite remote sensing as a proven technology in ocean sciences, we recognize Stan Wilson's achievements.

This item was contributed by Christopher N. K. Mooers, *Past-President, Ocean Sciences Section; Joseph L. Reid, President; and* Peter G. Brewer, *former Secretary.*

World Ocean Circulation Experiment: Planning for a U.S. Component

A World Ocean Experiment (WOCE) to improve our description and understanding of the world ocean circulation is being planned. Technological and scientific developments of the last decades have made possible the serious consideration of such a global experiment to begin in the late 1980's. These developments include an increased understanding of the nature of ocean circulation and the sampling procedures needed to observe it, instrumentation for long time series measurements, numerical ocean models and high-capacity computers to use them, improved methods for measurement of chemical tracers, the means for obtaining improved ocean measurements from vessels of opportunity, satellite technology that can observe both the primary atmospheric forcing and the oceanic response, and the realization that addressing global societal problems related to the ocean will require a coordinated, global-scale program of ocean observation and modeling.

The WOCE is considered to be a contribution to the study of long-term climate trends and sensitivity (Stream 3) of the World Climate Research Program (WCRP). At the international level the formulation is being guided by a Scientific Steering Group under the auspices of the Committee on Climatic Changes and the Ocean and the Joint Scientific Committee of the WCRP.

The provisional goals for an international WOCE are (1) to collect the data necessary to develop and test ocean models for predicting climate change and (2) to determine the representativeness of the specific WOCE data sets for the long-term behavior of the ocean and find methods for determining long-term changes in the ocean circulation. Since the focus is on the construction of ocean models and the collection of data sets necessary for demonstrating that these are useful models of the ocean circulation, the determination of what these data sets should be is the crux of the WOCE design. The International Scientific Steering Group has established a Numerical Experimentation Group and six working groups in different areas to consider what major data sets are required and to determine strategies for obtaining the required data.

On the basis of present concepts it seems likely that the major elements of WOCE will include models, satellite altimeters, a satellite gravity mission, satellite scatterometers for surface winds, other fields of surface forcing, hydrography, tracer measurements, direct velocity measurements, acoustic tomographic arrays, ship-of-opportunity programs, and a data management system. Many of these elements must be coordinated with the proposed

Oceanography *(cont. on p. 734)*

News & Announcements

W. Stanley Wilson: AGU Ocean Sciences Award

The Ocean Sciences Section of the AGU recognizes W. Stanley Wilson for his unique leadership contributions to the emerging role of satellite measurements in oceanography. Through his persistent efforts the ocean sciences now stand on the brink of a new era that will merge conventional research techniques with new satellite technologies.

Stan completed his B.S. and M.A. degrees at the College of William and Mary. He spent three years as a research biologist in Australia, New Zealand, and Antarctica before obtaining a Ph.D. in oceanography from The Johns Hopkins University in 1972.

He then joined the Office of Naval Research (ONR) as a program manager for physical oceanography. Promoted to program director for physical oceanography in 1976, he helped to develop and manage outstanding multi-institutional programs that included the Mid-Ocean Dynamics Experiment (MODE), the North Pacific Experiment (NORPAX), and the Mixed Layer Experiment (MILE). Stan was highly successful in integrating and translating the new research results into Navy operational use. For these efforts, he was awarded the Department of the Navy Superior Civilian Service Award in 1979.

In 1979, Stan accepted a new challenge with NASA as Chief of the Oceanic Processes Branch in the Office of Space Science and

Oceanography *(cont. from p. 733)*

satellite missions scheduled for the 3- to 5-year lifetimes to begin in 1989. Others must begin earlier (now) and continue throughout the most intensive operational phase and beyond.

Each participating country is expected to develop a national plan which might contribute in the areas of its capability and interest to the overall experiment. Within the United States this planning process began with a workshop on "Global observation and understanding of the general circulation of the oceans" for some 60 members of the U.S. oceanographic community. The weeklong workshop was organized under the auspices of the National Research Council (NRC) Board on Ocean Science and Policy and held during August 1983 in Woods Hole, Mass. The workshop participants agreed that the WOCE concept is worthwhile and timely, identified a tentative U.S. goal and objectives, and recommended that a U.S. planning committee and a number of working groups be established to address critical issues. The provisional objectives of the U.S. component of WOCE are directed toward describing and understanding global ocean circulation. It was felt that this understanding is important for itself and must precede an understanding of the role of the ocean in climate.

The workshop report received wide distribution and review, and a panel for the U.S. WOCE was constituted within the NRC, sponsored jointly by the panels of the Board on Ocean Science and Policy and the Board on Atmospheric Sciences and Climate. That panel has been moving toward the design of a U.S. WOCE component. Initial support for the panel activities has been provided via the NRC and by a grant from the National Science Foundation to the Joint Oceanographic Institutions Inc. Several U.S. working groups (closely coordinated with the international groups) have been established; communication links between the U.S. scientific community, the sponsoring agencies, and the international components are being implemented; and a proposal for an intensive planning activity for the fiscal years 1985–1987 has been prepared.

To date, U.S. working groups have been formed to plan WOCE activities in the following areas: measurement and interpretation of tracers, experimental design for measuring geostrophic circulation, surface forcing (wind stress and heat and moisture fluxes), numerical modeling, data management, and technology development. In addition, other ad hoc group meetings and activities by interested groups of scientists are being supported.

To inform the community of the activities of the panel, working groups, and ad hoc groups, we plan to publish, in TOR, brief reports of meetings and other items of interest. In this issue we include the report of a Deep Drifters Meeting held in Denver, Colo., on May 18–19, 1984. Interested scientists should contact panel members, meeting chairpersons, working group members, or the U.S. WOCE Planning Office: W. Nowlin, Department of Oceanography, Texas A & M University, College Station, TX 77843 (telephone: 409-845-2947; telemail: Sciencenet, W. Nowlin).

New Research Vessels

Two "new" ocean-going research vessels operated by the Scripps Institution of Oceanography and the National Science Foundation (NSF) will soon begin full-time scientific duties off the coast of California and in the Antarctic, respectively. The 37.5-m Scripps vessel, named *Robert Gordon Sproul* in honor of the ex-president of the University of California, replaces the smaller ship *Ellen B. Scripps*, which had served the institution since 1965. The new ship is a slightly modified Gulf Coast workboat. Under the name of *Midnight Alaskan*, it had been used for high-resolution geophysical surveys in American and Latin American waters by such firms as Arco Oil & Gas, Exxon, Pennzoil, and Racal-Decca before its purchase by Scripps from a Louisiana chartering firm last summer.

The *Robert Sproul* is undergoing a number of modifications for scientific outfitting, including the addition of laboratories, winches, booms, and electronic and research instruments. The ship will be used mainly along the California coast and in the Gulf of California for biological investigations, physical oceanography, and scientific equipment testing. Its maiden voyage, however, scheduled for early September, will take it to Yucatan, Mexico, for a study of seals, then on to the west coast of Mexico for in-transit studies of marine mammals and birds. The *Robert Sproul* is expected to return to its home port of San Diego by late October, and to make its first voyage along the California coast in support of physical oceanography experiments in late autumn. Meanwhile, the *Ellen B. Scripps* is being offered for sale, with the proceeds to be used to pay for the new ship.

The new NSF Antarctic research ship, *Polar Duke*, will replace the wooden-hulled *Hero*, which has served in the Antarctic since 1968. The new ship is larger (65.7 m versus 37.5 m), and its hull is classified as strong as that of an ice-breaker. It will have room for approximately 40 people (some 2–3 times *Hero*'s capacity), will carry more laboratory equipment, and will have a helicopter deck. As a result, it will be able to conduct research in the rough waters between South America and Antarctica that was impossible with the aging *Hero*. The new ship's cargo space is being converted to laboratories in preparation for its first scientific voyage on or about January 1 of next year. The *Polar Duke* will support antarctic research in biology, oceanography, and geology. Originally designed for scientific and transport expeditions, the vessel is being leased from Carino Shipping Limited of Newfoundland by ITT/Antarctic Services, who will operate the ship for the NSF for a period of 3 years. There is also a provision for two 1-year extensions. *Hero*, meanwhile, will be retired after 16 years of operations in Antarctic waters, and current plans are to dispose of it as government surplus.

Meetings

Deep Drifters Meeting

Technical development of a new generation of deep drifting systems is proceeding at several locations. A meeting was held in Denver, Colo., on May 18–19, 1984, under the joint sponsorship of the National Research Council (NRC) Panel for a U.S. World Ocean Circulation Experiment (WOCE) and the Drifters development program. The purpose was to discuss the state of development of these systems, their prospects for continued development, and their possible use in programs such as WOCE, where the intended spatial and temporal sampling scales are quite large. The three new systems discussed were RAFOS (SOFAR spelled backwards), the General Circulation Drifter, and Dyogene. The capabilities of existing Sound Fixing and Ranging (SOFAR) floats were also discussed.

The expectation of remotely sensed data from satellites as part of the WOCE has prompted consideration of what types of in situ instruments are most suitable for use with such data. Satellite data approaches global spatial coverage and continues over years, with a temporal resolution between a few days and a month. Very few in situ measurement systems can approach these sampling characteristics without heroic effort and extraordinary expense. Drifting buoy systems, which report sensor data and/or position through satellite systems, such as the present System ARGOS, hold great promise for achieving sampling characteristics which are compatible with satellite data if they can be made sufficiently inexpensive to be deployable in large numbers. The focus of this meeting was on drifting buoys capable of measuring interior ocean currents by passive drift.

A major objective of WOCE is to determine the transports of heat, salt, and other chemical properties over large distances due to both systematic (mean) and irregular (diffusive) advection. Traditionally, these transports have been inferred largely from the spatial distributions and knowledge of sources and sinks. These inferences can be made in principle with more confidence for transient property fields (e.g., bomb radiocarbon and tritium). However, as a complement to such indirect methods, the long-time trajectories of deep drifting buoys may provide important direct information about the capacity of the general circulation for transport of passive water properties.

The Global Circulation Drifter (GCD) is under development by Doug Webb at Webb Research Corporation in collaboration with Russ Davis at Scripps Institution of Oceanography. It is designed as a free-drifting vehicle which will operate down to 2000 m and be capable of several round trips to the surface to report its position by ARGOS. The design is for a lifetime of 10 years and of approximately 40 round trips to the surface, which might be extended to 200 with further development. The GCD is undergoing testing at sea in 1984.

RAFOS is a buoy which drifts at the depths of the sound channel. It is under development by Tom Rossby at the University of Rhode Island. In addition to temperature and pressure, RAFOS stores the time of arrival of signals from fixed SOFAR sound sources three times a day. At the end of its design lifetime (presently 6 months) the float surfaces and telemeters its stored data through ARGOS. The sound sources are moored in the area of interest on simple moorings. The usable range from source to the RAFOS float is about 1500 km, though this will vary geographically depending on the water characteristics. Acoustic sources have an expected lifetime of perhaps 2.5 years, which might be extended to 5 years with additional development. Similarly, the lifetime of the RAFOS floats themselves probably can be extended to beyond a year. This system will be used in the Gulf Stream and adjacent regions during the period 1984–1986.

Dyogene is under development by J. C. Gascard in France. It is a deep drifter designed to sample for periods of about 1000 days, with data subsets of about 100 days being reported via ARGOS during a round trip to the surface. Dyogene rises by releasing ballast and descends by releasing buoyancy in the form of glass balls. A 1-month test on the surface confirmed the performance of the data-reporting system, including a low-profile antenna. Depth cycling tests are planned next. A pilot experiment with a limited number of buoys will be carried out in late 1986 or 1987. The lifetime of Dyogene is presently limited by the life of the lithium batteries. It could be extended by using solar rechargeable cells.

SOFAR floats have been used in a variety of locations and experiments since the late 1960's. In its original form the system consisted of drifting sources and shore-based receivers. Later innovations include the use of a moored recoverable receiver, the Autonomous Listening Station (ALS), which frees the experimenter from the geographical constraints of working near existing shore stations. An even more recent development is the RELAYS (Real-Time Link and Acquisition Yare) system, which may be regarded as a drifting ALS. This system is being tested during 1984. The present expected lifetime of SOFAR floats is about 2.5 years, which can be expected to be increased with better quality control but minimal redesign. About 50% of the floats deployed have lasted to their energy limit (battery life). SOFAR floats may drift at various depths in the range 500–2000 m, with the best performance (greatest range) obtained in the sound channel.

Contemplating the use of drifters in large-scale experiments as part of the WOCE leads to the question of operational feasibility. Experimental design may suggest the use of 1000 floats in an ocean basin. How are such large numbers of floats to be prepared and deployed? Will it be necessary to establish new facilities to carry out this operational activity and relieve the burden on the more experiment-oriented academic institutions? Such facilities might handle the drifting floats, moored sources, and moored Autonomous Listening Stations.

The ARGOS transmitter is a substantial part of the cost of construction of a drifting buoy. Less expensive ARGOS-approved Platform Transmit Terminals (PTT) with position accuracy of about 5 km (lower than present) may be commercially obtainable. An accuracy of 5–10 km would be adequate for the buoys under discussion, and a lower-cost PTT should be sought and approved for ARGOS use.

The discussion of a plan for deep drifters in WOCE addressed two general questions: For what purposes would one want the deep drifter data? How many drifters would be needed? The proposed purposes were analyses of mean horizontal velocity and velocity variance (eddy kinetic energy), dispersion of drifters (hence horizontal diffusivity), mapping of the very large scale and low frequency velocity field, and pathways of the general circulation, i.e., displacements over distances larger than individual eddy scales. For each purpose one can determine how many drifters are required to achieve a given degree of success.

These determinations have, as yet, been made only very crudely. However, there was general agreement that something near 1000 drifter years of data in an ocean basin the size of the North Atlantic would make a significant contribution to each of these purposes. (This assumes moderately frequent location reporting, which is more easily accomplished for acoustically tracked drifters, and moderately uniform horizontal distribution.) A crude illustration of the basis for this number, most relevant to the first of the purposes above, follows. One thousand drifters, reporting weekly for a year and uniformly distributed in an area equal to a 4000-km square, would give 50 nearly independent samples of low-frequency velocity on a grid spacing of about 125 km. This would determine the mean with an accuracy better than 1 cm/s for a standard deviation of 5 cm/s. If the analysis grid were coarse, the accuracy would be better for the same number of drifters, or the same accuracy would be achieved with fewer drifters.

The following points relevant to future development of buoy systems were made:

- The RAFOS receiver should be put in the GCD (or Dyogene) vehicle, providing a multiply recycling, acoustically traced drifter.
- These floats should be aimed at intermediate depths. The flow at extreme depths is more topographically controlled and therefore harder to interpret in a general circulation context, while the shallower depths (above 500 m) can probably be measured with cheaper drogued surface buoys. (SOFAR and RAFOS are inherently restricted to intermediate depths in any case, because of the need for reasonably long acoustic ranges.)
- Effort should be put into the technical aspects of combining RAFOS, SOFAR, and ocean acoustic tomography in future experiments, using a mutually compatible system of acoustic sources.
- Consideration should be given to adding data telemetry to the SOFAR Autonomous Listening Stations to allow "real-time" processing of data. The Moored Oceanographic Instrumentation System (MOIST) program at Woods Hole Oceanographic Institution might provide the technology base to make this possible.
- Both ships-of-opportunity and aircraft should be considered for buoy deployment, and each buoy system should be so planned.

This new generation of intermediate depth drifting floats will provide new tools for the general circulation investigator. Their capabilities are such that a selection or mix of float types may be called for in a given experiment, depending on experimental design and location. There are intriguing possibilities for synergistic combinations between various types of floats and between the floats and other new technology, such as tomography.

Acknowledgments

Funding for the WOCE planning activity was provided by the National Science Foundation; support for the Drifters program has been provided by the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration and the Office of Naval Research.

This report was submitted by Robert Heinmiller *of Omnet, Inc. and* James McWilliams *of the National Center for Atmospheric Research (NCAR).*

News *(cont. from p. 729)*

eruption on the southern part of the fissure had ceased except on one crater, which then changed into phreatic activity.

"On the northernmost part of the fissure, activity continued as of the morning of 12 September with significant lava production. By 8 September, inflation rates over the magma chambers diminished and slow deflation started.

"As in previous eruptions, lava production was highest on the northern part of the fissure and has so far not constituted any threat to inhabited areas."

Information Contacts: Karl Grönvold, Nordic Volcanological Institute, University of Iceland, Reykjavik, Iceland; Páll Einarsson, Science Institute, University of Iceland, Reykjavik, Iceland.

Meteoritic Events

Fireballs: Canada; Czechoslovakia; Netherlands; Tasman Sea; California, south-central states, Massachusetts, Oregon, Wisconsin, USA; Zimbabwe.

Earthquakes

Date	Time, UT	Magnitude	Latitude	Longitude	Depth of Focus, km	Region
Aug. 6	1907	6.8 M_s	32.40°N	131.81°E	50	Off Kyushu, Japan
Aug. 17	1806	3.9 m_{bLg}	37.82°N	78.39°W	6	SW Virginia, USA

Information Contacts: National Earthquake Information Service, U.S. Geological Survey, Stop 967, Denver Federal Center, Box 25046, Denver, CO 80225.

Books

Groundwater Contamination

Panel on Groundwater Contamination of the Geophysics Study Committee of the National Research Council, National Academy Press, Washington, D. C., xii + 179 pp., 1984.

Reviewed by R. Allan Freeze

Since 1977, the National Research Council (NRC) has published 13 monographs in its *Studies in Geophysics* series. Earlier volumes have dealt with such diverse topics as energy and climate, geophysical prediction, continental tectonics, and explosive volcanism. *Groundwater Contamination* is the 14th volume in the series. It was produced by a Panel on Groundwater Contamination initiated by the Geophysics Study Committee of NRC in consultation with representatives of the supporting agencies and members of the scientific community. The preliminary scientific findings formed the basis of an American Geophysical Union symposium in San Francisco in December 1981. This monograph is the most concise and most accessible reference available on this important environmental problem.

The report consists of 14 chapters authored by well-known researchers in the field and an overview of the study that summarizes the highlights of the chapters and formulates conclusions and recommendations. The 14 chapters are arranged in five groups: 1, Background (one chapter); 2, Processes (two chapters); 3, Methods of Waste Disposal (two chapters); 4, Examples (seven chapters); and 5, Institutional Aspects (two chapters).

The Background chapter by Veronica Pye and Jocelyn Kelley of the Academy of Natural Sciences of Philadelphia assesses the extent of groundwater contamination in the United States on the basis of two independent regional surveys that have been carried out, one by the Environmental Protection Agency and one by the Environmental Assessment Council. They conclude that cases of groundwater contamination have been documented in all parts of the country but that "we are still in a position to make choices on how best to use, manage, and protect this valuable resource."

The chapters on Processes by Mary Anderson of the University of Wisconsin and John Cherry and his coworkers of the University of Waterloo provide an up-to-date assessment of our physical and chemical understanding of the movement of contaminants in groundwater. While the current advection/dispersion/retardation approach is capable of mimicking observed behavior, it is now clear that it does not represent an understanding of the transport processes at the fundamental level required. There is still much to be learned with respect to organic contaminants, transport in fractured rock, and the questions of scale that surround the slippery concept of dispersion.

To my mind, the heart of this book lies in the seven case histories presented in part 4. It is in the individual tales of mismanagement, realization, and reclamation that the difficulties in measurement, assessment, and prediction become clearest. Many of the most visable of the well-known recent contamination incidents are here: The Love Canal in New York, the Rocky Mountain Arsenal in Colorado, the Llangollen landfill in Delaware, and the low-level nuclear waste dumps at Hanford, Washington, and Maxey Flats, Kentucky. The description of the aquifer reclamation project at the Rocky Mountain Arsenal by Leonard Konikow of the U.S. Geological Survey and Douglas Thompson of the U.S. Army Corps of Engineers is a particularly valuable case history.

In the Overview prepared by the panel, there are four recommendations that appear in italics:

1. *Research is needed on the effects of chemical reactions on transport and dispersion of contaminants by groundwater and the quantification of flow in fractured media.*
2. *There should be a more thorough search for disposal sites that can be used safely to isolate toxic wastes from the biosphere for long periods.*
3. *A strategy [should] be developed that provides for the segregation, treatment, and disposal of wastes according to their hazards and their chemical affinities.*
4. *Governmental and industrial organizations need to agree whether various classes of wastes should be disposed of locally or in regionally designated repositories.*

This is a valuable book. It will undoubtedly be used for readings in many hydrogeology seminars, and it is well suited to this purpose. But it is even more important that its message reach environmental engineers, designers of waste disposal systems, administrators of local and state agencies, and lawyers and legislators.

R. Allan Freeze is a professor in the Department of Geological Sciences at the University of British Columbia, Vancouver, Canada.

Physical Geology: Principles and Perspectives

E. A. Hay and A. L. McAlester. Prentice-Hall, Englewood Cliffs, N.J., 1984

Reviewed by James W. Skehan, S.J.

Textbooks on physical geology have proliferated over the past 20 years or more, during which time most fields have undergone a subject matter explosion. The challenge of authoring such a textbook is to accurately summarize the most important factual and theoretical results and to present the material in a pedagogically attractive and meaningful manner. The authors mainly have met that challenge.

Basically, I could teach the course quite happily using this book as the text. An attractive feature is that the authors have summarized those aspects of the science with which I am most familiar in a generally acceptable and interesting manner. This includes excellent line drawings and block diagrams calculated to be very helpful to the student. Those chapters dealing with areas of the authors' scientific expertise are understandably stronger and smoother than some others. A useful perspective for the beginning student and teacher is an explicit discussion of geology as a science with a comparison and contrast of methods and results in relation to other fields of science.

The chapters are brief enough to provide a readable overview. Following the treatment of classification and principles, a number of chapters have several pages illustrating the foregoing by an analysis of regional geological features of considerable general interest, such as Yosemite, Kings Canyon, and Sequoia National Parks noted for igneous activity, for example. Each chapter has an abbreviated, useful outline of the main points covered and several appropriate references for additional reading. Many chapters have interesting, short single topic treatments ("boxes") (e.g., "The Driving Mechanism Behind Plate Tectonics"). The book is a good teaching vehicle because, with notable exceptions, it is easy to supplement the text in class with one's own favorite illustrations. Such an exception is chapter 2, "Basic Building Blocks—Matter and Minerals," which would be more effective if abbreviated, and some of the exquisite detail of crystal chemistry stored in an appendix for one who needs a fuller explanation.

There are a few incomplete sentences, inexact or awkward usage of terms such as silicon for silica, or "ultramafic igneous rocks and serpentine" (p. 285), omission of sheeted dikes in description of ophiolites, or neglect of the solar wind in the consideration of the shape of the lines of force of the earth's magnetic field (p. 299, Figure 7.16), for example. These are all mainly items that proofreaders and paid consultants will remedy for the second printing of this revised edition, no doubt. A number of the photographs (black and white) tend to be too dark or are otherwise of inferior quality (e.g., Figure 4.25b) and detract from the generally outstanding quality of the line drawings.

This is an attractive book mainly because it is a carefully abbreviated summary of most of the topics and is very well illustrated, notably with line drawings. The pedagogically useful references to the relationships between geology and the needs of mankind, chapter summaries, vignettes of regional geology classics, "boxes," and additional readings, and a good quality glossary and index outweigh the negative points noted above. In general, such features of this revised edition should render it quite competitive with some of the other books of quality now available.

James W. Skehan, S.J., is director of Weston Observatory and professor of geology, Department of Geology and Geophysics, Boston College, Weston, MA 02193.

Nonlinear Waves

Lokenath Debnath (Ed.), Press Syndicate of the University of Cambridge, New York, 360 pp., 1983.

Reviewed by Dennis Papadopoulos

The book *Nonlinear Waves* edited by L. Debnath is a collection of papers on the theory and applications of nonlinear wave phenomena. The book is an outgrowth of an NSF-CBMS regional research conference on nonlinear waves and integrable systems, convened in June, 1982 at East Carolina University. The book aims at bringing together recent developments on the theory of nonlinear waves and solitons, with selective applications in the areas of fluid dynamics and plasma physics. The field had an explosive growth during the last decade, and it is, correctly, expected that it will exert a major influence on future research directions of many fields of physics and engineering.

The book is divided into three parts. The first two deal primarily with applications of the mathematical techniques for solving nonlinear equations to special problems in the fields of fluid dynamics and plasma physics. The third part deals mainly with applied mathematics and focuses on recent results and extensions of the inverse scattering transformation (IST), of the evolution equations, and of the statistical mechanics of the Sine-Gordon Hamiltonian. A total of 18 papers are included in the volume, seven on fluid dynamics, five on waves and solitons, and six on applied mathematics. Taken individually, almost all of the papers are well written reviews of important subjects in their specific fields, including a variety of recent and exciting results and techniques. Of particular interest are the fluid mechanics chapters 2–5, along with chapters 16 and 17 of the applied mathematics part, which discuss a variety of solutions of the Korteweg-deVries (KdV) and nonlinear Schrödinger (NLS) equations for systems with and without dissipation, including the role of variable coefficients. A general nth order spectral transform and its inversion and the role of recurrence are also presented in an interesting fashion.

Unfortunately, that is as far as I can point to any kind of unifying tie among the various chapters of the book, and even in this case I am stressing it. The level of mathematical sophistication is so uneven as to make most of the book rather unreadable on any level of general physics, applied mathematics, or engineering audience. I do not believe that the desired cross fertilization among the nonlinear hydrodynamicists, plasma physicists, and applied mathematicians can be accomplished with this book. It is possible that this could have been achieved through the discussions at the conference; nevertheless, as often happens in similar cases, the followup manuscripts tend to be more sophisticated and spe-

Books *(cont. on p. 736)*

Books *(cont. from p. 735)*

cialized, breaking the unifying tie achieved through the usually simple physical presentations in the research conference.

The subject of nonlinear dynamics, including applications to physics and engineering, has made tremendous strides during the last decade. The sooner the general scientific public becomes familiar with it, the sooner we will have major breakthroughs in the understanding of many subjects in physics and engineering. Several excellent books with good descriptions of both the fundamental mathematical theory of IST and spectral methods as well as applications to fluid dynamics, plasma physics, and solid state have appeared recently. Ablowitz and Segur, "Solitons and the Inverse Scattering Transform," and Lamb, "Elements of Soliton Theory," are examples of such books, although they stress the subject of conservative systems. The role of dissipation and of strange attractors is adequately treated in *Topics in Nonlinear Dynamics*, edited by S. Jorna, as well as the proceedings of the various "Twente" Conferences. I believe that referring to the above references, especially the Ablowitz and Segur volume, can much better accomplish the goals set by the editor of the book under review here. Meanwhile, *Nonlinear Waves* can remain a collection of good review articles on the subject of nonlinear waves, but with only the title as the unifying entity.

Dennis Papadopoulos is with the Department of Physics, University of Maryland, College Park, MD 20742.

New Publications

Items listed in New Publications can be ordered directly from the publisher; they are not available through AGU.

Acid Rain: A Water Resources Issue for the 80's, R. Herrmann and A.I. Johnson (Eds.), American Symposium on Hydrometeorology, iii + 83 pp., 1983.

Acoustic Waveguides: Applications to Oceanic Science, C.A. Boyles, John Wiley, New York, xii + 321 pp., 1984, $46.95.

The Coevolution of Climate and Life, S.H. Schneider and R. Londer, Sierra Club Books, $25.

Deconvolution, A. Ziolkowski, International Human Resources Development, Boston, Mass., xii + 175 pp., 1984, $36.

Gas Transfer at Water Surfaces, W. Brutsaert and G.H. Jirka (Eds.), D. Reidel, Hingham, Mass., x + 639 pp., 1984, $78.

Heat Conduction, U. Grigull and H. Sander, (Transl. by J. Kesin), Springer-Verlag, xx + 187 pp., 1984.

Helium Isotopes in Nature, B.A. Mamyrin and L.N. Tolstikhin, *Dev. in Geochem.*, vol. 3, Elsevier, New York, xiv + 273 pp., 1984, $53.75.

International Symposium on Hydrometeorology, A.I. Johnson and R.A. Clark (Eds.), American Water Resources Association, Bethesda, Md., ix + 598 pp., 1983.

Kimberlites, I, Kimberlites and Related Rocks, J. Kornprobst (Ed.), *Dev. in Petrol. 11A*, Elsevier, New York, xiv + 466 pp., 1984, $55.75.

Kimberlites, II, The Mantle and Crust-Mantle Relationships, J. Kornprobst (Ed.), *Dev. in Petrol. 11A*, Elsevier, New York, xiv + 398 pp., 1984, $50.

The Major Biogeochemical Cycles and Their Interactions, B. Bolin and R.B. Cook (Eds.), John Wiley, New York, xxi + 532 pp., 1983.

The Morphostructure of the Atlantic Ocean Floor: Its Development in the Meso-Cenozoic, V.M. Litvin, (Transl. by V.M. Divid, N.N. Protsenko and Y.U. Rodzhabov), D. Reidel, Hingham, Mass., ix + 172 pp., 1984, DFL 95.

The Near-Earth and Interplanetary Plasma, vol. 1: General Properties and Fundamental Theory, V. L. Alpert, Cambridge University, New York, Mellourne,, viii + 209 pp., 1983, $59.

The New Science of Strong Materials, J.E. Gordon, 2nd ed., Princeton University, Princeton, N.J., 287 pp., 1984, $9.95.

Nitrogen in the Marine Environment, E. J. Carpenter and D. G. Capone (Eds.), Academic, New York, xvii + 900 pp., 1983, $59.

Noble Gas Geochemistry, M. Ozima and F. A. Podosek, Cambridge Univ., New York, vii + 365 pp., 1983, $79.50.

Nonlinear Waves, L. Debnath (ed.), Cambridge University, New York, 360 pp., 1983, $39.50.

Ophiolites: Oceanic Tectonics and Metamorphism, Suppl. 8, Ofiolita, Pitagora, Bologna, 73 pp., 1983.

Our Threatened Climate: Ways of Averting the Problem Through Rational Energy Use, W. Bach (Transl. by J. Jäger, D. Reidel, Hingham, Mass., xxiv + 368 pp., 1984, $29.

Palaeoclimatic Research and Models, A. Ghazi (Ed.), D. Reidel, Hingham, Mass., vii + 205 pp., 1983, $34.50.

Permafrost: Fourth International Conference Proceedings, July 17–22, 1983, Organized by University of Alaska and National Academy of Sciences, National Academy Press, Washington, D.C., xxv + 1524 pp., 1983.

Phosphate Minerals, J.O. Nriagu and P.B. Moore (Eds.), Springer-Verlag, New York, vi + 442 pp., 1984, $57.50.

Physical Geography: A Landscape Appreciation, T. L. McKnight, Prentice-Hall, Englewood, NJ, xix + 488 pp., 1984.

Physical Geology: Principles and Perspectives, 2nd ed., E. A. Hay and A. L. McAlester, Prentice-Hall, Englewood Cliffs, NJ, xii + 463 pp., 1984, $25.95.

Physical Oceanography of Coastal Waters, K. F. Bowden, *Ellis Horwood Ser. in Mar. Sci.*, New York, 302 pp., 1983, $68.95.

The Polarization Method of Seismic Exploration, E.I. Gal'perin, D. Reidel, Hingham, Mass., xiv + 268 pp., 1984, $58.

Precambrian of South India, S.M. Naqvi and J.J.W. Rogers (Eds.), *Mem. 4*, Geological Society of India, Bangalore, xx + 575 pp., 1983.

Principles of Lake Sedimentology, L. Håkanson and M. Jansson, Springer-Verlag, New York, x + 316 pp., 1983, $59.

Problems and Prospects in Long and Medium Range Weather Forecasting, D.M. Burridge and E. Källen (Eds.), *Topics in Atmos. and Oceanage Sci.*, Springer-Verlag, New York, vi + 274 pp., 1984, $17.50.

Proceedings of the Biomass Colloquium in 1982: Special Issue, No. 27, T. Nemoto and T. Matsuda (Eds.), *Mem. of Nat. Inst. of Polar Res., Spec. Issue 27*, National Institute of Polare Research, Tokyo, iv + 247 pp., 1983.

Proceedings of the Third Symposium on Antarctic Geosciences, 1982: Special Issue, No. 28, T. Nagata (Ed.), National Institute of Polar Research, Tokyo, iv + 289 pp., 1983.

Proterozoic Geology, L. G. Medaris, Jr., C. W. Byers, D. M. Mickelson, and W. C. Shanks (Eds.), *Mem. 161*, Boulder, Colo., viii + 315 pp., 1983.

Regional Trends in the Geology of the Appalachian-Caledonian-Hercynian- Mauritanide Orogen, Paul E. Schenk (Ed.), *NATO ASI Ser., Ser. C: Math and Phys. Sci.*, vol. 116, D. Reidel, Hingham, Mass., xiii + 598 pp., 1983, $53.50.

Remote Assessment of Ocean Color for Interpretation of Satellite Visible Imagery, H. R. Gordon and A. Y. Morel, Springer-Verlag, New York, 114 pp., 1983, $20.

Revolution in the Earth Sciences: Advances in the Past Half-Century, S. J. Boardman (Ed.), Kendall/Hunt, Dubuque, Iowa, viii + 385 pp., 1983.

Rock and Mineral Magnetism, W. O. Reilly, Blackie, Chapman and Hall, New York, xi + 220 pp., 1984, $39.95.

Rock Fracture Mechanics: No. 275, H. P. Rossmanith (Ed.), Springer- Verlag, New York, xii + 484 pp., 1983, $34.

The Role of Heat in the Development of Energy and Mineral Resources in the Northern Basin and Range Province, Special Report No. 13, Geothermal Resources Council, v + 384 pp., 1983, $30.

Scale-Up of Water and Wastewater Treatment Processes, N.W. Schmidtke and D. W. Smith (Eds.), Butterworth, Boston, pp., 1983, $39.95.

Science and Creationism: A View from the National Academy of Sciences, Committee on Science and Creationism, National Academy of Sciences, National Academy Press, Washington, D.C., 28 pp., 1984, Quantity: 1, $4; 2–9, $3; 10 or more, $1.75.

Sediment Diagenesis, A. Parker and B. W. Sellwood, (eds.), D. Reidel, Boston, vii + 427 pp., 1983, $53.50.

Seismic Design Technology for Breeder Reactor Structures, vol. 1, *Special Topics in Earthquake Ground Motion*, D. P. Reddy (Ed.), Agbabian Associates, El Segundo, Calif., ix + 267 pp., 1983, $23.50.

Seismic Design Technology for Breeder Reactor Structures, vol. 2, *Special Topics in Soil/Structure Interaction Analyses*, D. P. Reddy (Ed.), Agbabian Associates, El Segundo, CA, vii + 126 pp., 1983, $14.50.

Seismic Design Technology for Breeder Reactor Structures, vol. 3, *Special Topics in Reactor Structures*, D. P. Reddy (Ed.), Agbabian Associates, El Segundo, CA, vii + 159 pp., 1983, $16.

Seismic Design Technology for Breeder Reactor Structures, vol. 4, *Special Topics in Piping and Equipment*, D. P. Reddy (Ed.), Agbabian Associates, El Segundo, CA, vii + 207 pp., 1983, $19.

The Technology of High-Level Nuclear Waste Disposal: vol. 1, P. L. Hofmann and J. J. Breslin, (eds.), Technical Information Center, U.S. Department of Energy, Oak Ridge, Tenn., xii + 395 pp., 1981, $18.

Theoretical Glaciology: Material Science of Ice and the Mechanics of Glaciers and Ice Sheets, K. Hutter, *Math. Approaches to Geophys.*, D. Reidel, Hingham, Mass., xxxii + 510 pp., 1983, $104.

Treatment Plant Hydraulics for Environmental Engineers, L. D. Benefield, J. F. Judkins, Jr. and A. D. Parr, Prentice-Hal, Englewood Cliffs, NJ, 281 pp., 1984, $39.95.

Tsunamis: Their Science and Engineering, K. Lida and T. Iwasaki (Eds.), *Ad. in Earth and Planet. Sci.*, D. Reidel, Boston, xiv + 563 pp., 1983, $113.

United States Earthquakes, 1981, C.W. Stover (Ed.), U.S. Geological Survey, Reston, Va., 1984, $5. *Water Resource Planning and Development*, M.S. Petersen, Prentice-Hall, Englewood Cliffs, N.J., xvii + 316 pp., 1984, $35.

Wandering Continents and Spreading Sea Floors on an Expanding Earth, L. C. King, Wiley-Interscience, New York, x + 232 pp., 1983, $29.95.

Water Management Models in Practice: A Case Study of the Aswan High Dam, D. Whittington and G. Guariso, Elsevier Scientific, New York, xvii + 246 pp., 1983, $63.75.

Water Resources: Distribution, Use, and Management, J. R. Mather, J. Wiley & Sons, New York, xv + 439 pp., 1984, $40.

Water Wave Mechanics: For Engineers and Scientists, R. G. Dean and R. A. Dalrymple, Prentice-Hall, Englewood Cliffs, NJ, xi + 353 pp., 1984, $34.95.

Waves on Fluid Interfaces, R. E. Meyer (Ed.), Academic, New York, ix + 359 pp., 1983, $25.

Zeo-Agriculture: Use of Natural Zeolites in Agriculture and Aquaculture, W. G. Pond and F. A. Mumpton (eds.), Westview, Boulder, xii + 296 pp., 1984, $52.50.

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University of California, Santa Barbara. Tenure track position in geography-oceanography, available July 1, 1985. Salary and rank are dependent upon qualifications; however, preference will be given at the Assistant Professor level. The Geography Department seeks applicants with backgrounds in Physical Oceanography and/or Air/Sea Interaction with an interest in Remote Sensing. Applicants must have a Ph.D., substantial qualifications in marine research, and a strong commitment to teaching and research. Submit resume and names of three referees to: Chairman, Search Committee, Department of Geography; University of California; Santa Barbara, CA 93106. Closing date: December 10, 1984.
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Yale University/Solid Earth Geophysics. The Department of Geology and Geophysics is soliciting applications for a junior faculty position in solid-earth geophysics to begin in the academic year 1985–1986. Areas of interest to the department include seismology, exploration geophysics, mechanical and physical properties of rocks and minerals, geomagnetism, tectonophysics, and geodesy. Curriculum vitae, publications and the names of three or more referees should be sent by December 1, 1984 to Karl K. Turekian, Chairman, Department of Geology and Geophysics, Yale University, Box 6666, New Haven, CT 06511.

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The Department has 11 full-time faculty. In addition, two faculty from the Physics Department participate in our geophysics program. Complete geophysical instrumentation, including a seismograph station and rock mechanics lab, are available.

Interested persons should send resume, statement of research interests, official transcripts, and three letters of reference to Charles M. Onasch, Chairman, Search Committee, Department of Geology, Bowling Green State University, Bowling Green, Ohio 43403. The closing date is November 30, 1984. We will be interviewing at GSA in Reno.

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Letters of application should be accompanied by a resume that includes a description of research interests and accomplishments and teaching experience, a list of publications, and the names of at least three references. Send to: S.O. Schlanger, Chairman, Department of Geological Sciences, Northwestern University, Evanston, Illinois 60201. Closing date for applications is November 1, 1984. We expect to fill the position for the fall of 1985.

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Scripps Institution of Oceanography/Geochemistry. Applications are invited for a tenure track faculty position in the general field of geochemistry and petrology, including inorganic/physical marine chemistry, marine biogeochemistry, geochemistry of sedimentary, metamorphic, and igneous rocks, fluid-rock interactions, theoretical and experimental petrology, and organic geochemistry. The position will involve graduate-level teaching and the supervision of graduate student research. The level of the appointment will depend on the applicant's qualifications. Applicants must hold Ph.D. degree and have demonstrated excellence and independence in research. Associate or professorial level candidates must demonstrate a strong research record in their specialization; assistant level candidates will be expected to show evidence of their potential through publication record appropriate for their experience and letters of recommendation. Send letter of application and curriculum vitae, including description of research interest, and names of three references to: Chairman, Graduate Department, A-008, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA 92093. Closing date for applications is 1 November 1984.

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Solid-earth geophysics (to complement two seismologists joining our staff in January 1985) — preference will be given to a person with research interest in heat flow, potential fields, or geophysical modeling.

Applicants should send resume, transcripts, and names and addresses of three references to:
Tom Freeman, Chairman
Department of Geology
University of Missouri
Columbia, MO 65211.

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Senior or Senior Project Hydrogeologist/Hydrologist. A newly-formed hydrogeology and engineering consulting firm, The Mark Group, seeks a mature, experienced hydrogeologist or hydrologist for an immediate filling of senior technical positions in the Las Vegas and Pleasant Hill, California offices. Ongoing and projected investigations will emphasize water resources development, hazardous waste, and geotechnical engineering projects. Principal project work is in California, Nevada, and Arizona. Prefer applicants with minimum four years similar experience and MS degree. Strong written and verbal communication skills and overall initiative are required. Professional registration in geology or engineering desirable. Salary and bonus commensurate with training, experience and productivity. Ownership participation anticipated. Please send resume and references to:
Dr. Robert F. Kaufmann, Principal
The Mark Group
801 S. Rancho Drive, Ste. D-3A
Las Vegas, NV 89106
702-384-4747.

6TH INTERNATIONAL CONFERENCE ON BASEMENT TECTONICS

September 16–20, 1985
Santa Fe, New Mexico

Sponsored by
INSTITUTE FOR GEOPHYSICS AND PLANETARY PHYSICS
AT
LOS ALAMOS NATIONAL LABORATORY
AND
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Interdisciplinary conference on nature, origin, and reactivation histories of large-scale fractures and major structural features in the crust of the earth and other planets. Basement deformation and regional tectonic studies.

SPECIAL SYMPOSIA:
1. Basement Controls on Mineralization
2. Basement Tectonics and Chronology of Precambrian Rocks, Mid-continent Region, USA
3. Basement Controls on the Development of Intracontinental Rifts

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CONFERENCE COMMITTEE
General Chairman – M. J. Aldrich
Program Chairman – A. W. Laughlin
Arrangements Chairman – L. Maassen

FIELD TRIPS–
1. Colorado River raft trip in Grand Canyon – 6 days.
2. Colorado River raft trip in Grand Canyon – 4 days.
3. Bright Angel and Kaibab trails trip in Grand Canyon.
4. Western Jemez Mountains.
5. Northern Rio Grande Rift.

There will be invited and contributed presentations. Abstract deadline is February 1, 1985. Obtain a brochure and abstract form from the Program Chairman:
A. William Laughlin
Mail Stop D462
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Pre-conference Workshop
PARAMETERS CONTROLLING THE DISTRIBUTION OF LARGE ORE DEPOSITS, ORE CLUSTERS, MINERAL BELTS, AND METALLOGENIC PROVINCES
September 15, 1985
Sponsored by
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For information write to: Jan Kutina
Laboratory of Global Tectonics and Metallogeny
c/o Dept. of Chemistry American University
Washington, D.C. 20016

High Altitude Observatory Scientific Visitor Program/NCAR. Scientific visitor appointments at the High Altitude Observatory are available for new and established Ph.D's for up to one year to carry out research in solar physics, solar-terrestrial physics, and related subjects. Applicants should provide a curriculum vitae, including education, work experience, publications, the names of three scientists familiar with their work, and a statement of their research plans. Applications must be received by 15 January 1985 and they should be sent to: The HAO Visitor Committee, High Altitude Observatory, National Center Atmospheric Research, P.O. Box 3000, Boulder, Colorado 80307-3000.

NCAR is an Equal Opportunity/Affirmative Action Employer.

University of Utah Structual Geology/Tectonics/Tectonophysics. The Department of Geology and Geophysics at the University of Utah seeks applications for a tenure track position in structural geology, tectonics or tectonophysics. It is anticipated that this position will be filled at the assistant professor level, but applications by more senior persons will be considered. The position requires a Ph.D. with emphasis in structural geology, regional tectonics or tectonophysics. The new faculty member will have the opportunity to teach in the area of his or her specialty and may also be assigned introductory level courses. The successful candidate will be expected to establish a vigorous research program involving graduate students. The person who fills this position will join an active program in structural geology and tectonics that includes both field projects and integrated geology/geophysics and mechanics/fluid chemistry studies of structures in the western Cordillera. There is an excellent opportunity to collaborate with other faculty in structural geology, sedimentology, geophysics, geochemistry and petrology. A vita, copies of publications, names of three persons that may provide references, and a letter outlining the candidate's research and teaching interests should be sent to Dr. William P. Nash, Chairman, Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah 84112-1183. Deadline for receipt of applications is December 31, 1984 with the appointment starting in September 1985.

The University of Utah is an equal opportunity/affirmative action employer.

Physical Oceanographers. The Physical Oceanography Branch of the U.S. Naval Oceanographic Office seeks full-time Oceanographers for the study of the effects of oceanic current and thermal/density structure on undersea systems using data collected from various platforms for a variety of projects. The projects involve the collection, analysis and reporting of physical oceanographic data directly applicable to relevant Navy environmental requirements. Up to 50% field duty may be required.

Multiple vacancies at the GS-7, 9 and 11 levels are available depending upon qualifications and experience and will remain open until filled. Salary range: $17,221 to $35,139.

Please contact (for required forms): Debra Staples, #(202)-282-0431, Commercial 601-688-5720, Autovon 485-5720, or FTS 494-5720, U.S. Naval Oceanographic Office, Management & Personnel Division, Personnel Operations Branch, Code 4320, Bay St. Louis, NSTL, Mississippi 39522.

Solid Earth Geophysicist. Faculty position at the Graduate Department of Scripps Institution of Oceanography and the Institute of Geophysics and Planetary Physics. Applications are invited for a tenure track faculty position in the field of solid Earth geophysics, including its theoretical and observational aspects. The position will involve graduate level teaching and the supervision of graduate student research. Qualifications include a Ph.D. in one of the sciences and demonstrated excellence and independence in research. Weight will be given to evidence of superior teaching ability. An appointment at the Assistant Professor level is envisaged but qualified applicants at all levels will be considered. Associate or professorial level candidates must demonstrate a strong research record in their specialty; assistant level candidates will be expected to show evidence of their potential by means of a publication record appropriate for their experience and in their letters of recommendation. Salary commensurate with qualifications and experience. Send letter of application, curriculum vitae, including research interests, and the names of three references to: Chairman, Graduate Department A-008, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA 92093. Responses must be received by November 30, 1984.

An equal opportunity/affirmative action employer.

Department of Geology and Geophysics/University of California, Berkeley. Subject to final budgetary approval, the Department is authorized to make two faculty appointments, one at the senior level and one at the junior level, and anticipates making two further appointments next year. Applicants with an outstanding record of research in any field of geology and geophysics are encouraged to apply. The ability to carry out leading research, as well as an interest in teaching graduate and undergraduate students, are major factors in the selection. Applications, including the names of at least three references, should be sent by December 15, 1984 to the Search Committee, Department of Geology and Geophysics, University of California, Berkeley, California 94720.

The University of California is an equal opportunity/affirmative action employer.

Position Available/University of Hawaii. Postdoctoral Fellowship, full time, salary $22,000–$24,000. One-year appointment, to begin approximately January 1, 1985, with second year contingent on availability of funds.

A researcher with a background in meteorology or atmospheric physics is needed to join an ongoing study of local atmospheric properties at Mauna Kea Observatory, one of the world's most renowned sites for ground-based astronomy. We aim to (1) characterize the local microclimate at the mountain top, and (2) study clear air turbulence above the site. Highly advanced state-of-the-art meteorological instrumetnation, now in place at the site, will be used as a basis for the study.

The candidate will be required to spend some time on Mauna Kea, although most work will be done in Honolulu at the Institute for Astronomy (IFA), one of the forefront centers for research in asronomy. The IFA is part of the University of Hawaii and close to the UH Department of Meteorology. Collaboration with the Department of Meteorology will be encouraged.

We seek a candidate with knowledge of physical meteorology and/or upper atmospheric physics. A basic background in synoptic meteorology is required, and familiarity with measurement systems is desirable. Minimum Qualifications: Ph.D. in Meteorology, Atmospheric Physics, or a related field; a proven record as a researcher as demonstrated by publications (or equivalent experience); and recommendations by peers.

Applications should be sent to: Dr. Don Hall, Director, Institute for Astronomy, 2680 Woodlawn Drive, Honolulu, Hawaii 96822, so as to arrive by November 30, 1984. Further inquiries can be directed to Dr. Laird Thompson, phone 808-948-8102.

The University of Hawaii is an equal opportunity/affirmative action employer.

HYDROLOGIST/ GEOHYDROLOGIST

Excellent growth opportunity in environmental research and services. Will lead development of research programs to identify flow and transport of chemical substances and mitigate environmental impact.

We need an individual with a PhD in Hydrology or Geohydrology plus at least two years field experience in groundwater monitoring, flow and transport modeling and environmental impact mitigation. Equivalent education/experience, e.g., an MS and more extensive related experience, will be considered.

Our location offers an excellent quality of life for anyone who values a clean environment, abundant outdoor recreation and a small town, university atmosphere. Apply by sending your credentials, salary requirements and references to:

Manager of Personnel Services
WESTERN RESEARCH INSTITUTE
University of Wyoming Research Corporation
P.O. Box 3385 University Station
Laramie, Wyoming 82071

WRI is an equal opportunity employer.

Geophysicist/University of North Carolina. The Department of Geology invites applications for a tenure track faculty position in solid-earth geophysics beginning July 1, 1985. The position probably will be at the assistant professor level, but candidates at the associate professor level will be considered. The Ph.D. is required, and post-doctoral experience is desired. Our preference is for a seismologist and/or tectonophysicist, who would complement current departmental activities, but any good applicant in geophysics will be considered.

Faculty members are expected to conduct a visible and active research program, teach graduate and undergraduate students, and supervise theses.

Inquiries and letters of application should be sent to P. Geoffrey Feiss, Department of Geology 029A, University of North Carolina, Chapel Hill, NC 27514. Applications must include a resume, a statement of research and teaching interests, and the names of at least three references. Closing date for applications is October 19, 1984.

UNC is an affirmative action/equal opportunity employer.

Research Geophysicist: Closing Date Extended from October 5 to November 2, 1984. The U.S. Geological Survey (USGS), Office of Earthquakes, Volcanoes, and Engineering, Branch of Seismology is soliciting interest from exceptionally well-qualified persons with either a record of demonstrated ability or outstanding potential for research in one or more areas of Branch activity. The Branch of Seismology conducts fundamental research in the fields of earthquake prediction, network seismology, crustal structure and volcano seismology. The Branch is particularly interested in a geophysicist with expertise in the field of seismology.

All interested persons should submit a detailed resume of education, experience, summary of interests and research interactions, and the appropriate salary level commensurate with experience by 2 November 1984 to:

William Ellsworth
U.S. Geological Survey
Branch of Seismology
345 Middlefield Road, MS-977
Menlo Park, CA 94025.

Should a position become available in the Branch, you will be notified of the competitive Federal employment application requirements.

The U.S. Geological Survey is an Affirmative Action/Equal Opportunity Employer.

William M. Rice University/Marine Geophysics. The Department of Geology invites nominations and applications for the W. Maurice Ewing Chair in Oceanography. We are seeking applicants for a new position in marine geophysics to fill this chair.

The Department of Geology has recently added two reflection seismologists to its faculty and is building a state-of-the-art seismic processing facility.

The successful applicant will be expected to teach graduate and undergraduate courses and to develop a strong research program in his or her area of interest. Cooperation in ongoing research with other members of the Rice faculty and faculty at other Texas universities would be encouraged.

Send enquiries and applications to Dr. Albert Bally, Chairman, Department of Geology, Rice University, Houston, Texas, 77251–1892. Applications should include a detailed resume, the names and addresses of three references, and a statement of research interests.

Rice University is an equal opportunity/affirmative action employer.

College of Geosciences/University of Oklahoma. Applications and nominations are invited for the position of Director of the School of Geology and Geophysics. The Director is expected to have a Ph.D. or equivalent, a strong, ongoing research program and administrative experience; industrial experience helpful; field of geological specialization open; to begin July 1, 1985; salary to be negotiated.

In 1980, the School will move into the new 300,000 sq. ft. Energy Center along with other elements of the College of Geosciences: the Oklahoma Geology Survey; and the School of Petroleum and Geological Engineering and the School of Chemical Engineering and Materials Sciences, both from the College of Engineering.

Applications with curriculum vitae, names and addresses of three references, and/or nominations should be sent to:

Francis G. Stehli, Dean
College of Geosciences
University of Oklahoma
601 Elm Street, Room 438C
Norman, Ok 73019.

Consideration of applications will begin January 1, 1985.

The University of Oklahoma is an Equal Opportunity/Affirmative Action Employer.

Dean
College of Mathematical and Physical Sciences

The Ohio State University invites nominations and applications for the position of Dean of the College of Mathematical and Physical Sciences. The College consists of seven departments: Astronomy, Chemistry, Geodetic Science and Surveying, Geology and Mineralogy, Mathematics, Physics, and Statistics. Undergraduate, masters, and doctoral degree programs are offered in each department. Included in the College is an undergraduate program in computer and information science in cooperation with the Department of Computer and Information Science (College of Engineering), an interdisciplinary major in mathematical sciences, a major in actuarial science, and a major in Engineering Physics. The Materials Research Laboratory is an interdisciplinary program at the graduate level which involves Physics, Chemistry, Metallurgical Engineering, and Ceramic Engineering.

The College has a faculty of 230 FTE and teaches over 9,000 students (FTE) per year. Several of its departments are among the most distinguished in the University.

The Dean provides leadership as the chief executive of the College and promotes the goals of the College, departments and programs; the Dean reports to the Provost of the University. Qualifications for the position include a distinguished scholarly record in research and teaching plus demonstrated leadership and administrative ability. Candidates must qualify for a tenured appointment in one of the departments of the College at the level of Professor. The deanship is a twelve-month position.

Position available July 1, 1985, or at an earlier date. Salary is negotiable and commensurate with background and experience. Nominations or letters of application, curriculum vitae, and names, addresses, and telephone numbers of four references are required.

The Search Committee will begin to review dossiers on October 10 and will continue to receive nominations and applications until a candidate is selected.

Applications and nominations should be addressed to:

Chair, Search Committee for a Dean of the
College of Mathematical and Physical Sciences
The Ohio State University
Office of Academic Affairs
203 Bricker Hall
Columbus, Ohio 43210

Bureau of Mineral Resources, Australia: Senior Research Scientist/Principal Research Scientist. Applications are invited from suitably qualified men and women for the position of Senior Research Scientist (SRS)/Principal Research Scientist (PRS).

BACKGROUND: The ability to detect and identify nuclear explosions is an important element in achieving the Australian government's objective of seeking a Comprehensive Test Ban treaty which would ban all nuclear tests by all states in all environments. A National Monitoring Centre (NMC) and an International Data Centre (IDC) are being established to assist the international monitoring of nuclear explosions by seismological means. This group of ten scientific and technical staff will be established within the Bureau of Mineral Resources, Geology and Geophysics. The leader of the Group will report to the head of the Earthquake Seismology Section within the Division of Geophysics.

The initial task of the Group Leader (SRS/PRS) will be to arrange facilities to carry out the monitoring and data analysis roles and to develop these into an operating system.

DUTIES: To direct the operations of the NMC and the IDC for the seismological monitoring of nuclear explosions.

QUALIFICATIONS: Admission to degree of Doctor of Philosophy or equivalent qualification together with considerable experience in seismological research is essential. Experience in managing a scientific team, the science of monitoring nuclear explosions, seismological data processing, signal enhancement techniques, and digital data processing would be advantageous.

SALARY: Senior Research Scientist $A32,367—37,274; Principal Research Scientist $A38,686—45,041.

Classification will depend on the successful candidate's qualifications and experience.

CONDITIONS: Conditions of service include superannuation, long service leave, four weeks annual leave and removal expenses to Canberra.

APPLICATIONS: Together with full personal and professional details and the names of at least three referees should be sent to:

The Director
Bureau of Mineral Resources
PO Box 378
CANBERRA CITY A.C.T. 2601
AUSTRALIA

By 26 October 1984.

Civil Engineering. The University of Notre Dame is seeking applications for a tenure track Assistant or Associate Professor position in the Department of Civil Engineering. Applicants should have an earned Ph.D. in Civil Engineering or an appropriately allied discipline; the initiative, scholarship, and creativity to direct a funded research program encompassing M.S. and Ph.D. students; and a demonstrated ability for quality teaching at the graduate and undergraduate levels. The successful candidate will strengthen the Department in at least one of the following areas: water quality, hydrology, environmental chemistry, soil mechanics, geotechnical engineering, design or structural analysis. Appointment will begin with the Fall 1985 semester or other agreed upon date. Send resume and names of three references to: William G. Gray, Chairman, Department of Civil Engineering, University of Notre Dame, Notre Dame, IN 46556.

Affirmative Action/Equal Opportunity Employer.

Old Dominion University/Marine Organic Geochemist—Search Extended. The Department of Oceanography seeks candidates for a newly created, state-funded tenure track faculty position in marine organic geochemistry. Specific research interest is open, although the major departmental emphasis is on coastal processes. The successful candidate is expected to pursue a vigorous funded research program, and to teach undergraduate and/or graduate level courses in his/her field. The expanding Oceanography Department offers programs leading to the M.S. and Ph.D. degrees. It currently has 15 faculty positions, with three in chemical oceanography, 70 graduate students, and the appropriate facilities for many chemical studies. The position will be at the assistant professor level. A Ph.D. is required and post doctoral experience is desirable. The position is available for the 1985-86 academic year. Applicants should submit a vita, statement of research interests and the names of three references by October 31, 1984 to: Dr. Gregory A. Cutter, Search Chairman, Department of Oceanography, Old Dominion University, Norfolk, VA 23508, 804-440-4285.

ODU is an affirmative action/equal opportunity institution.

Signal Processing and Control Systems Scientific Engineering Positions. Available at B.S., M.S., and Ph.D. level in the following R&D areas: Digital Signal Processing—design and analyze algorithms, conduct data analysis with emphasis on detection, estimation and spectrum analysis. Control Systems Engineering—design and analyze digital/analog adaptive control. A working familiarity with FORTRAN is required. Working closely with other highly skilled professionals, individuals will participate in an environment that nurtures self-directed achievement. U.S. citizenship is required; current DOD security clearances desired. Submit resume to Dr. David Feinblum, Technical Director, XYBION CORPORATION, 240 Cedar Knolls Road, Cedar Knolls, New Jersey 07927.

University of Wisconsin—Madison. The Department of Geology and Geophysics invites applications for an anticipated tenure track position at the assistant professor level in applied geomorphology and/or hydrogeology commencing in August 1985. The applicant should be committed to developing a strong research program as well as teaching undergraduate courses in some aspects of engineering and environmental geology. The Ph.D. is required. Applicants with course work in engineering and an interest in the field application of geologic principles are especially encouraged to apply. Send letter of application outlining your professional goals, transcripts, resume, copies of publications, and three letters of reference to Dr. Mary P. Anderson, Department of Geology and Geophysics, Weeks Hall, University of Wisconsin, Madison, WI 53706. Closing date is January 1, 1985.

The University of Wisconsin is an equal opportunity/affirmative action employer.

Physical Scientist: Department of Commerce, National Oceanic and Atmospheric Administration (NOAA). The National Environmental Satellite, Data, and Information Service (NESDIS), Office of Research and Applications (ORA) announces a vacancy for the position of physical scientist, GS-1301-13, Suitland, Maryland. Vacancy closes October 31, 1984. The successful applicant will perform basic and applied research in physical sciences with emphasis on the land sciences using imagery and physical measurements collected by meteorological and land resource satellites. The purpose of these investigations is to increase knowledge and understanding of hydrologic, climatological, and land-related phenomena and processes, and to develop applications of remote sensing data to hydrologic, climatological and land-related problems. The position requires a demonstrated ability in scientific research on the application of remote sensing to the above stated problems, as evidenced by publications in the scientific literature. A Ph.D. in the physical sciences or equivalent, familiarity with programming of mainframe computers and experience with interactive digital systems are desirable. Persons interested in applying must request a copy of the vacancy announcement which contains qualification requirements, by writing to NOAA, FOB 4, Room 2051, Washington, D.C. 20233, ATTN: RASD:C24, Mary Queen, or calling 301-769-1986. Applications should be submitted on Standard Form 171.

Department of Commerce is an equal opportunity employer. U.S. citizenship required.

University of Rochester/Faculty Position. The Department of Geological Sciences at the University of Rochester invites applications for a tenure track position in sedimentology. Rank is open. Applicants must have an active research program and be committed to excellence in teaching. Applicants should submit a curriculum vitae and arrange to have three letters of recommendation sent to: Lawrence Lundgren, Chairman, Department of Geological Sciences, University of Rochester, Rochester, New York 14627.

The University of Rochester is an equal opportunity/affirmative action employer.

Manager, Research Computer Facility. The University of Oklahoma is looking for a person to manage a recently purchased VAX 11/785 computing facility dedicated to research in the Geosciences. Hardware and Software are designed for image processing, seismic reflection data processing, and graphical display of geological, geographical and geophysical data.

In addition to the 11/785 with 8mb of CPU memory, the system includes an array processor, live tape drives, five disk drives, a line printer, a 36" electrostatic plotter, and two high resolution graphics work stations with a digitizing board. The image processing hardware includes a Gould-DeAnza IP8500 processor with 16 image memory planes, real time disk memory and three high resolution color monitors.

The person selected must have at least a BS degree in science, math, engineering or related field; two years programming experience including FORTRAN; educational or computing experience in solid earth geophysics or meteorology. Experience with the VAX VMS operating system as well as supervisory experience preferred.

Salary is negotiable. People interested in the position should send a resume, copies of academic transcripts, and the names, addresses and telephone numbers of three references to:

John Wickham, Director
School of Geology & Geophysics
University of Oklahoma
Norman, OK 73019

Applications must be received by November 2, 1984.

POSITIONS WANTED

Geologist/Geochemist. 33, M.A., Ph.D. 1983. Specializing in low temperature geochemistry and geochronology with extensive experience in Rb-Sr mass spectrometry. Several publications. Seeks industry, academic research, or government position. Box 027, American Geophysical Union, 2000 Florida Avenue N.W., Washington, DC 20009.

Graduate Assistantships in Physics, Space Physics and Atmospheric Sciences. Assistantships are available for graduate students seeking M.S. and Ph.D. degrees in Space Physics, Atmospheric Sciences or Physics at the University of Alaska. Research areas include both Experimental and Theoretical studies in Space Plasma Physics, Solar Physics, Computational Physics, Radio Physics, Atomic and Molecular Spectroscopy, Atmospheric Optics, Atmospheric Dynamics, Atmospheric Chemistry, Physical Meteorology and Climatology. Thesis research is conducted through the Geophysical Institute. The stipend is $12,000 to $15,000 per year depending on credentials. Students with B.S. degrees in Physics, Atmospheric Sciences, Electrical or Mechanical Engineering are encouraged to apply. For more information, write to Professor J.R. Kan, Head, Department of Space Physics and Atmospheric Sciences, or Professor G. Sivjee, Head, Department of Physics, University of Alaska, Fairbanks, Alaska 99701 or call 907-474-7515.

Research Associate in Marine Geochemistry/Texas A&M University. Applications are invited for a position of Research Associate in the Department of Oceanography, Texas A&M University. Candidates should possess a Ph.D. and strong background in solution geochemistry or related area. Position will be for at least 1.5 years, to study actinide adsorption on mineral surfaces in the presence of organics. Starting salary $19,000 /year. Send letter of application, transcripts, resume and names and addresses of two references to: Dr. John W. Morse, Department of Oceanography, Texas A&M University, College Station, TX 77843.

University of Colorado/Visiting Faculty and Postdoctoral Fellowships for Research in Atmospheric and Climate Dynamics, Environmental and Atmospheric Chemistry, Environmental Biochemistry and Geochemistry. One year awards offered by the Cooperative Institute for Research in Environmental Sciences (CIRES). CIRES is supported by NOAA and the University of Colorado. Awards may be made to senior scientists, including those on sabbatical leave, or to recent Ph.D. recipients. Stipends average $25,000 for twelve months. The program is open to scientists of all countries. Selection of awardees is made in part on the likelihood of active interaction with CIRES scientists and other research groups in Boulder. Senior CIRES-affiliated scientists working in these fields include James Avery, Susan Avery, Ben Balsley, Roger Barry, John Birks, R. Ray Hall, Lang Farmer, Fred Fehsenfeld, William Hay, Murray Johnston, Bruce Koel, Eric Kraus, Uwe Radok, Robert Sani, Robert Sievers, and Harold Walton. Applications for the 1985–86 academic year awards should be sent to: Professor R. Sievers, Director of CIRES, Visiting Fellows Program, Campus Box 449, University of Colorado, Boulder, CO 80309. Include a vitae, publications list, and a brief outline of the proposed research. In addition, applicants should request that three persons familiar with their qualifications send letters of recommendation. Junior applicants should submit undergraduate and graduate transcripts. First consideration will be given to applications received by December 1. Final application deadline is February 15.

The University of Colorado is an affirmative action/equal opportunity employer.

Meetings

California Coastal Geology

October 20–21, 1984 National Association for Women Geoscientists Field Trip: California Coastal Geology, Burbank, Calif. (National Field Trip, AWG Los Angeles, P.O. Box 5041, Pasadena, CA 91107; tel.: Chris Bathker: 805-643-2154.)

This 2-day field trip on the California coast will allow participants to explore the productive Monterey formation and the Miocene volcanics and ophiolites of the San Luis Obispo area. Margaret Keller of the U.S. Geological Survey (USGS) will lead the Saturday trip to the Monterey Formation, and Sunday's outing will be led by Cathy Busby-Spera of the University of California at Santa Barbara.

Plan on San Francisco Now!
AGU Fall Meeting
December 3–7, 1984

Coastal Zone, Continental Shelf

Nov. 14–15, 1984 Coastal Zone and Continental Shelf Conflict Resolution, Cambridge, Mass. Sponsor: Massachussetts Institute of Technology Sea Grant Program. (T. Z. Henderson, MIT Sea Grant Information Center, 77 Massachussetts Ave., Building E38–301, Cambridge, MA 02139; tel.: 617-253-7041.)

The conference will explore traditional and non-traditional methods for resolving conflicts arising out of ocean and coastal resource use and development. Experts will discuss complex case histories involving scientific uncertainty and disagreement for which an approach, other than expensive, time-consuming litigation, could produce better results. Papers presented by legal, scientific, and management experts will cover problems areas such as the oil spill superfund, incinerator ship emissions, offshore leasing, effluent and oil pipelines, deep ocean mining, and boundary disputes. A look at the potential applications of alternate resolution techniques will include an examination of computer models, mini-trials, and various mediation techniques.

World Mining Congress

November 19–23, 1984 12th World Mining Congress, New Delhi, India. Sponsor: The Institution of Engineers (India). (The Institution of Engineers (India), SDI State Center, B. Shah Zafar Mrg 110002, New Delhi, India.)

The main theme of the Congress is "Optimal Exploitation of Solid Mineral Resources—Challenges and Constrains." Technical sessions will consider the following subthemes: Transformation of Resources in Reserves Through Improvements in Mining Technology and Resources Appraisal Methods; Improved Mineral Resources Through Exploitation Techniques in Coal, Metal and Non-Metal Mining Including Mining of Ore Bodies Under Adverse Geological Conditions; Conservation of Mineral Resources Including Solid Fuels; and International Exchange of Experience in the Development of Mineral Resources Through Improvements in Mining Technology and Evolution of a Mineral Policy. In addition to the technical sessions, there will be three round tables on the following themes: Education and Training of Mining Cadres, The Role of Small-Scale Mining, and Special Questions of Mining Technology and Safety in Mines. The Congress is coordinated with an International Mining Machinery Exhibition, which will run from November 14–28.

Deep Internal Processes

September, 1985 International Symposium on Deep Internal Processes and Continental Rifting, Chengdu, China. Sponsor: Chinese Lithospheric Committee (Claude Froidevaux, Université Paris-Sud, Lab. Geophysique-Bât. 510, 91405 Orsay, France).

Authors who wish to submit papers should notify the convenors by October 31, 1984.

The aim of this symposium is to coordinate research work on lithospheric problems. Suggested topics for discussion are the nature and origin of continental rifting structure and composition of crust and upper mantle, with combined application of seismic, electromagnetic, magnetic, paleomagnetic, gravimetric, and geothermic techniques; seismic activity and earthquakes; magmagenesis, including extrusion and intrusion, formation of ore bodies and kimberlites, and formation of oil reservoirs; petrological, geomorphological, and geochronometric investigations; and rheology of rocks and geodynamic modeling. There will also be a tour of the Panxi Rifting Belt, and a second tour in Northern China is being planned. The official languages of the symposium will be Chinese and English.

GAP

Separates

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Future AGU Meetings

Fall Meetings

Dec. 3–7, 1984, San Francisco, California. Call for papers appeared in July 3, 1984 *Eos*.

Dec. 9–13, 1985, San Francisco, California. Abstracts due mid-September 1985.

Dec. 8–12, 1986, San Francisco, California.

Spring Meetings

May 27–31, 1985, Baltimore, Maryland. Abstracts due early March 1985.

May 19–23, 1986, Baltimore, Maryland.

Regional Meetings

Front Range Branch Symposium on Geophysics and Geology of Yellowstone, October 25, 1984, Golden, Colorado. Abstracts due October 12, 1984; call for papers appeared in September 18, 1984 *Eos*.

Front Range Branch Hydrology Days, April 16–18, 1985, Fort Collins, Colorado. Abstracts due December 31, 1984 for professional hydrologists, February 15, 1985 for students; call for papers appeared in July 24, 1984 *Eos*.

Chapman Conferences

Vertical Crustal Motion: Measurement and Modeling, October 22–26, 1984, Harpers Ferry, West Virginia.

Solar Wind-Magnetosphere Coupling, February 12–15, 1985, Pasadena, California. Abstracts due November 1, 1984; call for papers appeared in July 10, 1984 *Eos*.

Ion Acceleration in the Ionosphere and Magnetosphere, June 3–7, 1985, Boston, Massachusetts.

Magnetotail Physics, October 28–31, 1985, Laurel, Maryland.

The last Geophysical Year calendar ran August 28, 1984, in *Eos*.

Scholarship Assistance
for Minority Students in Earth, Space, and Marine Science 1985—1986

The American Geophysical Union is once again pleased to participate in the American Geophysical Institute's Minority Scholarship Assistance Program. Approximately 70 awards from $500—$1500 are expected to be awarded for this term.

Eligible candidates are:

- Graduate or undergraduate students with good academic records;
- Enrolled in, or applying to, an accredited institution to study earth, space, or marine science;
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Aeronomy

0430 Composition (Molecular)
AN UPPER LIMIT FOR STRATOSPHERIC HYDROGEN PEROXIDE
K. V. Chance (Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138) and W. A. Traub

Measurements of an altitude-dependent upper limit for stratospheric hydrogen peroxide that is substantially lower than previously determined limits have been obtained. The data were obtained in thermal emission from the stratosphere with a far-infrared remote sensing spectrometer during a balloon flight on 23 January 1983. The 2σ upper limit vanishes a mixture of 0.65 ppbv near 26.5 km, corresponding roughly to the maximum in sampling sensitivity, and is larger above and below that altitude. This new upper limit is compared with two currently available modelling calculations for vibrating hydrogen peroxide; in the neighborhood of 32 km it is slightly lower than, but comparable to those theoretical profiles. The implications for assessment of HO_x at different latitudes and seasons are briefly discussed.

J. Geophys. Res., D, Paper 4D1105.

0430 Composition
SOLAR MESOSPHERE EXPLORER ULTRAVIOLET SPECTROMETER: MEASUREMENTS OF OZONE IN THE 1.0 TO 0.1 MB REGION
D.W. Rusch (Laboratory for Atmospheric and Space Physics, University of Colorado, Box 392, Boulder, Colorado, 80309), G.H. Mount, C.A. Barth, R.J. Thomas and M.T. Callan

The ozone density of the Earth's mesosphere in the 1.0 to 0.1 mb (48 to 70 km) region has been measured at sunlit latitudes for the period from December 1981 until the present by an ultraviolet spectrometer on the Solar Mesosphere Explorer satellite. Results for 1982 are reported. The ozone mixing ratios are found to be highly variable in time and place with maxima occurring in the winter hemisphere. The results show complex time variations at all pressures and latitudes. A relative maximum occurs in July at the equator.

J. Geophys. Res., D, Paper 4D1104.

0430 Composition (Atomic or Molecular)
ON THE DISTRIBUTIONS OF LONG LIVED TRACERS AND CHLORINE SPECIES IN THE MIDDLE ATMOSPHERE
Susan Solomon (Aeronomy Laboratory, National Oceanic and Atmospheric Administration, Boulder, Colorado 80303), and Rolando R. Garcia

A numerical model employing the residual Eulerian formulation and small eddy diffusivity coefficients is used to calculate the distributions of chemical tracers and chlorine species. The predicted densities of nitrous oxide, methane, and chlorocarbons are shown to be in good agreement with available observations, and to exhibit strong latitudinal gradients. Computed annual variations in methane produce large variations in the HCl and ClO densities. In particular, a pronounced local minimum in HCl is obtained near 40 km for certain latitudes and seasons, with a corresponding maximum in ClO, potentially of great importance for photochemistry. It is suggested that spatial and short-term temporal variability in methane has potentially important consequences for the HCl and ClO distributions in the atmosphere, and their variability, and for the chlorine catalyzed destruction of stratospheric ozone.

J. Geophys. Res., D, Paper 4D1158.

0430 Aeronomy (Composition)
STRATOSPHERIC HF MIXING RATIO PROFILES IN THE NORTHERN AND SOUTHERN HEMISPHERES
J. H. Park (NASA Langley Research Center, Chemistry and Dynamics Branch, Atmospheric Sciences Division, Hampton, Virginia, 23665), D. G. H. Russell, and H. L. Buijs

Stratospheric spectra obtained by two different balloon-borne Michelson interferometers have been analyzed using a nonlinear least-squares fitting method. The first differences in the HF mixing ratios reported earlier by other investigators have been shown to be less than previously indicated, although it has been found that stratospheric HF mixing ratios are apparently significantly larger in the northern than the southern hemisphere, the two HF profiles, however, show a similar vertical structure with an increase in the mixing ratio between 28 km and 25 km, an approximately constant value between 25 km and 35 km, and a further increase above 35 km, although the profile above 35 km remains somewhat uncertain. At the same time, the same spectra have been analyzed for CO_2 and H_2O mixing ratios for overlapping altitude ranges in order to provide confidence in the HF profile shape and mixing ratio values obtained. The HF profile shape as determined in this work is considerably different from the theoretically predicted profile.

J. Geophys. Res., D, Paper 4D0994.

0440 Winds
THE MERIDIONAL THERMOSPHERIC NEUTRAL WIND MEASURED BY RADAR AND OPTICAL TECHNIQUES IN THE AURORAL REGION
R. W. Wand (SRI International, Radio Physics Laboratory, Menlo Park, CA 94025), J. W. Meriwether, Jr., P. B. Hays, and A. F. Nagy

Radar observations of ion velocities in the magnetic zenith over Chatanika, Alaska, were used to determine the geomagnetic meridional component of the thermospheric neutral wind. Corrections for molecular diffusion and molecular ion contamination of the pure O^+ composition assumed for the ionosphere were included in the analysis. Comparison of the averaged diurnal variation of the meridional wind showed good agreement between the two measurement techniques. Good agreement was also found for several cases of simultaneous observations. The evidence suggested that differences were caused by gravity waves. The 7 years of near meridional wind results were examined with respect to magnetic activity, solar cycle phase, and season. During the day, the meridional component is poleward with a maximum of about 65 m/s between 1400 and 1600 local time. During the night, the wind is equatorward with a maximum of about 175 m/s between 0000 and 0300 local time. This nocturnal equatorward flow is near midnight, which is about 0130 local time. When the neutral wind is averaged for 24 hours, there is a large net equatorward flow. During periods of increased magnetic activity, the nighttime wind between 2300 and 0600 local time becomes stronger toward the equator. The average increase between 0200 and 0600 local time is about 100 m/s; however, on individual days it can be as large as 400 m/s. These data pertain mostly to equinox but the few summer and winter cases available to the date do not differ in the manner predicted by theory. Comparison of these results with theoretical models showed good agreement at most times, but suggested possible heating poleward of Chatanika during the morning hours. Observed exospheric temperatures increase poleward of this ionospheric (Maryland Point, Aengst Region, Incoherent-Scatter Radar, Fabry-Perot Interferometer).

J. Geophys. Res., A, Paper 4A1083.

0440 Tides, waves and winds
THERMOSPHERIC RESPONSE TO THE TOTAL 11, 1983 SOLAR ECLIPSE
R.G. Roble, R.E. Dickinson, and E.C. Ridley (all at National Center for Atmospheric Research,* P.O. Box 3000, Boulder, Colorado, 80307), and H.H. Kuo

The NCAR thermospheric general circulation model (TGCM) that includes coupling of dynamics and composition is used to calculate the time-dependent thermospheric response to the 11 June 1983 total solar eclipse. The path of totality originated at sunrise in the Indian Ocean near 33°S and 60°E. The path moved equatorward passing through Indonesia near 5°S latitude 125°E longitude and ending near 20°N latitude and 165°E longitude in the vicinity of the Solomon Islands. Although the path of totality is relatively small, the area of partial shadow is relatively large and the total flux incident on the dayside earth decreases by about 7% during the total eclipse. The TGCM calculates the time-dependent response of the winds, temperature, and composition resulting from the major constituents throughout the thermosphere. Perturbations follow the path of totality, with maximum deviations occurring near 0530 UT at about 250 km. The winds converge from all directions toward the shadow and speeds reaching 60 m s^{-1} in the upper thermosphere. The maximum temperature anomaly (~70°K) and vertical wind anomaly (~8 m s^{-1}) occur near the center of the shadow. The mean mixing ratio of O, along a constant-pressure surface decreases by up to 25 and that of O increases by up to 2X in response to the sudden thermospheric cooling caused by the shadow passing over the dayside of the earth. At a constant altitude of 300 km the N$_2$ and O number densities both decrease by about 6%. The time-dependent calculation shows that circulations are generated during the onset of the eclipse, with the largest perturbations following the path of totality.

*The National Center for Atmospheric Research is sponsored by the National Science Foundation

J. Geophys. Res., A, Paper 4A9010.

0499 General (Atmospheric Chemistry)
REACTION KINETICS OF O + CO_2 + CX > O_3 + CX BETWEEN 252–367 K
James J. Schwab (Department of Chemistry and Center for Earth and Planetary Physics, Harvard University, Cambridge, Massachusetts, 02138), D.W. Toohey, Wm. H. Brune and J.G. Anderson

A discharge flow system with laser magnetic resonance (LMR), resonance fluorescence (RF), and resonance-enhanced ionization (REA) detection modes is used to study the kinetics of the title reaction. Pseudo-first-order decays of O in excess CO and of ClO in excess O agree very well and yield a rate constant of $(3.5 \pm 0.4) \times 10^{-11}$ cm^3 molecule^{-1} s^{-1} over 300 K, with no discernable temperature dependence over the range 252 – 367 K. Both reactants, and for some experiments the O_2 atom product, are detected directly with high sensitivity. Experiments are done both in helium and in argon and the cited uncertainties include an estimate of systematic errors at the 2σ or 95% confidence level. Results are compared with other recent work and implications of the somewhat slower rate constant on the chlorine induced destruction of O_3 in the stratosphere are considered.

J. Geophys. Res., D, Paper 4D0997

Electromagnetics

0720 Electromagnetic theory
NUMERICAL ANALYSIS OF OPEN WAVEGUIDE DISCONTINUITIES
J. Ru, W.C. Chew (Electrical and Computer Engineering Department, University of Illinois, Urbana, Illinois 61801)

The spectral-iterative technique, a hybrid numerical method developed for scattering applications, is extended to [illegible] discontinuity problems. In this method, the fields in the region near the discontinuity are calculated numerically with the full wave iterative technique. Fields in the regions removed from the discontinuity are treated analytically using waveguide modes with unknown complex amplitudes. Field matching along the connecting surfaces yields an [illegible] matrix equation. Several methods for improving the convergence of the technique are discussed. (Dielectric waveguide discontinuity, numerical methods).

Rad Sci., Paper 4S0632.

0703 Antennae
THE EXCITATION OF PLASMA WAVES BY A CURRENT SOURCE MOVING IN A MAGNETIZED PLASMA: THE WKB APPROXIMATION
C. K. C. Nambudiri (Center for Atmospheric and Space Science, Utah State University, Logan, Utah, 84321), P. M. Banks and K. J. Harker

The excitation of low-frequency plasma waves arising from a current source moving through a cold, magnetized plasma is considered. In particular, the effects of motion of the source upon the radiation pattern are studied. In the present paper the general theory of wave excitation by a moving source is developed and specific approximations are made which are valid for frequencies much below the ion-cyclotron frequency. The amplitude and pattern of shear-Alfvén waves excited by a current source are studied for sources whose size in the direction of motion is large in comparison to the ion gyroradius and also for sources whose size is large in the direction of current flow ratio to comparison to the size of the source in other directions. It is shown that the radiation pattern of the shear waves arises naturally as a consequence of the motion of the source and that any modulation of the source current has little effect upon the wave, other than to reduce their amplitude. (wave excitation, moving source, WKB approximation, tethered satellite)

J. Geophys. Res., A, Paper 4A1090.

0770 Radio Oceanography
AIRCRAFT AND SATELLITE MEASUREMENT OF OCEAN WAVE DIRECTIONAL SPECTRA USING SCANNING-BEAM MICROWAVE RADARS
F. C. Jackson (NASA Goddard Space Flight Center, Code 671, Greenbelt, MD 20771), W. T. Walton and P. L. Baker

A microwave radar technique for remotely measuring the vector wave number spectrum of the ocean surface is described. The technique, which employs short-pulse, noncoherent radars in a conical scan mode near vertical incidence, is shown to be suitable for both aircraft and satellite application. The technique has been validated at 10 km aircraft altitude, where we have found excellent agreement between buoy and radar-inferred absolute wave height spectra. (Radar, satellites, ocean wave spectra).

J. Geophys. Res., C, Paper 4C1190.

Exploration Geophysics

0920 Magnetic and electrical methods
SIMULATION OF INDUCTION LOGGING BY THE FINITE-ELEMENT METHOD
Shu-Kong Chang (Schlumberger-Doll Research, P.O. Box 307, Ridgefield, CT 06877) Barbara Anderson

The response of an electromagnetic induction logging tool passing through many layered thin beds is simulated by the finite-element method. This simulation has achieved high accuracy by using a difference potential which enables the transmitter-receiver mutual coupling to be treated analytically. Consequently the removal of the mutual coupling from the induction tool response has no numerical ill effects. The finite-element model is truncated at a very large distance with a zero field outside the model. In order to achieve both accuracy and computational efficiency, the grid is projected to the truncation surface by gradually increasing its size according to an unlimited error analysis of the finite-element method. The numerical results were verified against analytical solutions for limiting cases and excellent agreement was obtained. In the presence of skin effect, which is beyond Doll's analysis by numerical factor theory, the finite-element solution conveniently provides a way to check and improve the interpretation of induction logs. It also lends itself to future applications in cased casing, signal processing, and conformity inversion schemes.

GEOPHYSICS, VOL. 49, NO. 11

0920 Magnetic and electrical methods
SYNTHETIC ELECTRIC SOUNDING SURVEYS OVER KNOWN OIL FIELDS
N.K. Garg (Geophysitic Resources Inc., 13465 S. Golden Road, Bldg. C, Golden, CO 80401) O.W. Keller

The possibility of using various types of electrical methods to locate oil or gas fields has been proposed in recent years. In an effort to quantify the anomaly to be expected with electrical sounding methods, average electrical parameters have been determined by applying a vertical well logs from several oil fields characterized by different geoelectrical sections. The do resistivity anomaly due to the presence of an oil-bearing layer at depth depends upon the sequence of resistivities above and below and the electrode array used. The radial dipole array gives the largest anomaly values, and is followed by the Wenner arrays such as the Schlumberger and Wenner arrays. The minimum anomaly for the apparent resistivity is observed when the resistivity beneath the target zone is lower than that above; the relative anomaly in apparent resistivity in these two cases is the contrast ratio of the transverse resistance of the oil-bearing layer to that of overlying beds. When the radial dipole array is used, a limited areal extent of the oil-bearing layer does not cause a significant change from the anomaly value due to a layer of infinite lateral extent. In that case the least dimension is about four times the depth. Use of one buried current electrode in the vicinity of the oil-bearing layer increases the amplitude of the anomaly; the maximum anomaly appears at a separation comparable to the depth.

Typical anomalies in apparent resistivity caused by these oil fields range from less than 0.1 percent to more than 10 percent. Such anomalies should be detectable only with an order of magnitude less than the capabilities of electrical sounding methods, or with considerably larger oil field targets.

GEOPHYSICS, VOL. 49, NO. 11

0920 Magnetic and electrical methods
IMPORTANT DESIGN CONSIDERATIONS FOR INBOARD AIRBORNE MAGNETIC GRADIOMETERS
C.D. Hardwick (Flight Research Laboratory, National Research Council, Montreal Road, Ottawa, Ontario, Canada K1A 0R6)

The advantages of magnetic gradiometry as an adjunct to total field mapping are generally recognized and a few aircraft have been equipped with gradiometers. These gradiometers are derived from high-sensitivity total-field magnetometer systems that are in themselves subject to certain errors that can usually be tolerated in conventional surveys. However, in a gradiometer, where very large total-field values are differenced, these errors can, in many cases, greatly exceed the basic accuracy required of the system.

There are two principal sources of error in inboard gradiometry systems. The first, and most significant, results from the inevitable magnetic interference of the aircraft or from the inability of currently available compensation systems to deal with the magnetic interference adequately. Passive methods of compensation are not sufficiently comprehensive for gradiometry and the active compensation systems currently in use, which were designed for military applications, cannot guarantee compensation at zero frequency (dc) or at the very low frequencies of interest to the geophysicist concerned with long-wavelength anomalies. The second source of error is the frequency-counting technique usually employed to convert a Larmor frequency to ambient total field. The counting process is somewhat analogous to digital sampling at a relatively low rate and as such affords little protection against aliasing from higher frequency interference sources, including components at aircraft maneuvering frequencies.

This paper, using examples, illustrates the two types of error. A list of design criteria is presented and several techniques are described for realizing these criteria. Finally, compensation and survey line results are shown for a three-axis gradiometer system in the National Research Council of Canada's Convair 580. This aircraft uses nonoriented cesium magnetometers, one in each wingtip and one at the tip of the tail fin. Compensations over the entire normal maneuver envelope of the aircraft on all headings give typical standard deviation errors of 3 my/m from dc to 1 Hz. Thus, the system is capable of measuring gradients down to nongeologic background levels.
GEOPHYSICS, VOL. 49, NO. 11

0920 Magnetic and electrical methods
THREE-DIMENSIONAL TERRAIN CORRECTIONS FOR MISE-À-LA-MASSE AND MAGNETOMETRIC RESISTIVITY SURVEYS
G.L. Oppliger (Formerly Engineering Geoscience group, University of California, Berkeley; presently Newmont Exploration Ltd., 200 West Desert Sky Road, Tucson, AZ 85704)

Three-dimensional modeling of topographic effects in mise-à-la-masse and magnetometric resistivity surveys is accomplished using the surface integral equation method. The technique provides a means for (1) analyzing these effects on earth models of homogeneous conductivity; and (2) removing terrain efects from field data.

A new method combining current source images with surface charge is developed to treat the electric field boundary conditions at the air-earth interface. The method uses an image of each subsurface current source positioned above the surface, so as to induce a surface charge distribution which approximately cancels the charge distribution induced by the subsurface current source. The resulting residual surface charge distribution varies spatially more gradually than either of the original charge distributions, and hence may be represented accurately on a coarsely segmented model surface with simple basis functions.

The topographic surface is modeled by a finite number of facets, each with constant slope and surface charge density. Charge values are obtained with an iterative solution technique. Surface electric fields are calculated from the surface charge distribution, current sources, and images. The magnetic field is found by evaluating a surface integral involving surface slopes and electric fields. The numerical solution is verified by comparisons with dipole-dipole resistivity results from a two-dimensional finite-element model of a valley, and with analytic solutions for the magnetic fields over a dipping interface. Methods for terrain correcting mise-à-la-masse and magnetometric resistivity data are demonstrated with examples using actual field measurements.

The results of this study show that (1) rugged topography can significantly distort measurements in mise-à-la-masse and magnetometric resistivity surveys, and (2) the described modeling technique provides an effective means of calculating terrain corrections for both the mise-à-la-masse and magnetometric resistivity methods over complex three-dimensional topography.
GEOPHYSICS, VOL. 49, NO. 10

0920 Magnetic and electrical methods
EXTREMAL BIAS COUPLING IN MAGNETOTELLURICS
L.B. Pedersen (Department of Solid Earth Physics, University of Uppsala, Box 556, S-751 22 Uppsala, Sweden) K. Svennekjaer

Bias effects due to uncorrelated noise on electrical and magnetic channels are cast into a quantitative framework which allows for an immediate conservative judgment of impedance tensor quality from a single station set up.

The horizontal magnetic field is regarded as input to a linear system with the horizontal electrical field and the vertical magnetic field as outputs. The coherence between inputs, the predicted coherence between outputs and inputs, and the polarization characteristics of the inputs determine the extremal bias effects.

Exact expressions for impedance tensor elements and tipper elements are given. Moreover, rotation angles of principal impedance direction, skew, and ellipticity are calculated.

Finally, we study some practical examples that show some of the characteristics predicted by our model.
GEOPHYSICS, VOL. 49, NO. 11

0920 Magnetic and electrical methods
NON-ORIENTED CESIUM SENSORS FOR AIRBORNE MAGNETOMETRY AND GRADIOMETRY
C.D. Hardwick (Flight Research Laboratory, National Aeronautical Establishment, National Research Council of Canada, Montreal Road, Ottawa, Ont., Canada)

Optically pumped magnetometers are characterized by an optimal angle between their optical axes and the direction of the magnetic field they are sensing. Departure from the optimal angle causes a shift in the Larmor frequency with a corresponding error in the scalar value of the magnetic field being measured. To minimize this error, magnetometers are conventionally either mounted in multiple sensor clusters such that the errors tend to cancel, or they are mechanically oriented to maintain the optimal angle with respect to the magnetic field vector.

Recent cesium vapor magnetometers using a split-beam technique have a sufficiently flat error characteristic that they can be flown in a non-oriented or "strap-down" configuration. This configuration has advantages with respect to conventional methods in terms of reduced size and weight and of greatly reduced cost. This paper describes two fixed orientations for a particular split-beam magnetometer and calculates the allowable maneuver envelope for all dip angles from 0 to 90 degrees. It is shown that the residual orientation errors can best be handled by the conventional type of magnetic interference compensation model that must, in any case, be implemented in digital form for high-sensitivity magnetometry or for any type of gradiometry.

The National Aeronautical Establishment (NAE) of the National Research Council of Canada has flown strap-down magnetometers in a three-axis gradiometer array in a Convair 580 for several years. Results for the entire normal maneuver envelope of the aircraft, including 30 degree bank turns, have equalled or surpassed those obtained with oriented magnetometers. Several typical maneuver compensation results are presented that gave root-mean-square (rms)(one-sigma) residual errors as low as 0.03 gammas (γ) for total field and 3.5 mgammas/m for lateral gradient.
GEOPHYSICS, VOL. 49, NO. 11

0920 Magnetic and electrical methods
DIFFRACTION OF AXISYMMETRIC WAVES IN A BOREHOLE BY BED BOUNDARY DISCONTINUITIES
W. C. Chew (Schlumberger-Doll Research, P.O. Box 307, Ridgefield, CT 06877) S. Barone, B. Anderson, and C. Hennessy

This paper presents the calculation of the diffraction of axisymmetric borehole waves by bed boundary discontinuities. The bed boundary is assumed to be horizontal and the inhomogeneities to be axially symmetric. In such a geometry, an axially symmetric source will produce only axially symmetric waves. Since the borehole is an open structure, the mode spectrum consists of a discrete part as well as a continuum. The scattering of a continuum of waves by bed boundaries is difficult to treat. The approach used in the past in treating this class of problem has been approximate in nature, or highly numerical, such as the finite-element method. We present here a systematic way to approximate the continuum of modes by discrete modes. After discretization, the scattering problem can be treated simply. Since the approach is systematic, it allows derivation of the solution to any desired degree of accuracy in theory; but in practice, it is limited by the computational resources available. We also show that our approach is variational and satisfies both the reciprocity theorem and energy conservation.
GEOPHYSICS, VOL. 49, NO. 10

0920 Magnetic and electrical methods
EFFECTS OF PIPELINES ON SPECTRAL INDUCED-POLARIZATION SURVEYS
Jorge O. Parra (Department of Geoscience, Southwest Research Institute, San Antonio, TX 78284)

The formal electromagnetic coupling solution for a dipole-dipole electrode array configuration has been modified to include cultural coupling in a uniform conducting half-space. Solutions are obtained for survey lines oriented at an arbitrary position and angle with respect to a cylindrical structure. The convergence properties of the general mutual impedance solution are analyzed using a low-frequency approximation which is useful in predicting cultural anomalies in the frequency range of spectral IP surveys as long as all significant dimensions are less than one skin depth. Both interfacial polarization and induced currents in the cylindrical conductor are considered in examining the behavior of the overall spectrum as seen by an external observer. Spectral responses for dipole-dipole arrays oriented perpendicular and parallel to the buried conductor show that the phase shift is the most diagnostic parameter for pipe depth and survey data distortion. The results also show that field survey procedures can be devised to minimize such interference effects when the pipe position is known.
GEOPHYSICS, VOL. 49, NO. 11

0930 Seismic methods
MULTIDIMENSIONAL LINEARIZED INVERSION AND SEISMIC MIGRATION
A.J. Berkhout (Delft University of Technology, Laboratory of Seismic and Acoustics, Postbus 5046, 2600 GA Delft, The Netherlands)

This paper discusses the close relationship between seismic migration and multidimensional inversion according to the linearized inverse scattering theory.

The linearized inverse scattering approach represents a mixed modeling-inversion procedure. Unlike seismic migration, the actual inversion process is carried out on the difference between a modeled reference response and the actually measured data. The output is generally presented in terms of the elastic parameters of the medium.

[illegible]

0930 Seismic methods
STABLE PLANE-WAVE DECOMPOSITION AND SPHERICAL-WAVE RECONSTRUCTION: APPLICATIONS TO CONVERTED S-MODE SEPARATION AND TRACE INTERPOLATION
[illegible]

[illegible]

Journal of Geophysical Research
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Calderas and Associate Igneous Rocks

[illegible]

0999 General or miscellaneous
THE INFLUENCE OF SALT DOMES ON PALEOTEMPERATURE DISTRIBUTIONS
[illegible]

0930 Seismic methods
OPTIMUM SEISMIC VELOCITY ESTIMATORS
[illegible]

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Volume 89 Number A10 October 1, 1984

Geodesy and Gravity

1905 Artificial Satellite Techniques
THE ORBIT OF LAGEOS AND SOLAR ECLIPSES
D. P. Rubincam (Geodynamics Branch, Code 921, NASA Goddard Space Flight Center, Greenbelt, MD 20771) and N.R. Weiss

An eclipse of the sun by the moon as seen by the Lageos satellite can affect the orbital semimajor axis at the centimeter level. The weakened radiation pressure acting on Lageos perturbs the orbit differently from that due to full sunlight. This difference amounted to less than 2 mm in the semimajor axis of 23 of the 30 eclipses Lageos experienced between launch in 1976 and the end of 1983. However, it was 17.6 mm for the eclipse on 28 March 1979 and 11.2 mm for the one on 16 December 1982. Differences such as these generate large enough along-track errors to make it worthwhile to include eclipses in complex orbit determination programs such as GEODYN which integrate the orbit. Eclipses cannot explain the presently unmodeled variations in along-track [illegible]

[illegible]

Some geoid lineations are oblique to both isochron and F.Z. trends; east of the Puerto Rico Trench such anomalies may reflect compressional deformation within Atlantic lithosphere. (Radar altimetry, shipborne gravity, North Atlantic sea-floor topography).

J. Geophys. Res., B, Paper 4B1173.

1930 High-order harmonics of the gravity potential field and local gravity anomalies
THE PRINCIPLE OF COMPLEX FREQUENCY SCALING—APPLICABILITY IN INCLINED CONTINUATION OF POTENTIAL FIELDS
R. Nagendra (Dept. of Geophysics and Centre of Exploration Geophysics, Osmania University, Hyderabad 500 007, India) N. Laxminarayana

A remarkable property of Fourier transforms, especially applicable to inclined continuation of potential geophysical fields, is the principle of "complex frequency scaling." Briefly stated, let $f(x)$ be the (gravity/magnetic) field due to a two-dimensional structure along a principal profile and $F(u)$ be its Fourier transform. The field along a profile passing [illegible]

[illegible]

with crustal age away from the Azores high is much greater than predicted by theoretical cooling curves. Correlation of residual geoid anomalies with depth, geochemical variations along the length of the Mid-Atlantic ridge and the chemistry of the Rio Grande Rise and Walvis Ridge suggest that many regions of anomalous residual geoid and crestal depth values may be in large part a function of crustal thickness and density variations induced by plume intrusion and volcanism in addition to their transient thermal effects. (Geoid anomalies, mantle plumes, hot spots).

J. Geophys. Res., B, Paper 4B1131.

Geomagnetism and Paleomagnetism

2530 Special variations (anomalies)
CRUSTAL STRUCTURE OF THE CHURCHILL-SUPERIOR BOUNDARY ZONE BETWEEN 80° AND 98° W. LONGITUDE FROM MAGSAT ANOMALY MAPS AND STACKED PASSES
D.H.Hall (Department of Earth Sciences, University of Manitoba, Winnipeg R3T 2N2, Canada), I.A. Noble and T.W. Millar.

A modeling technique using spherical shell elements and equivalent dipole sources has been applied to MAGSAT signatures at the Churchill-Superior boundary in Manitoba, Ontario and Ungava. A large satellite magnetic anomaly (12nT amplitude) on POGO and MAGSAT maps near the Churchill-Superior boundary was found to be related to the Richmond Gulf aulacogen. The averaged crustal magnetization in the source region is 5.2 Am^{-1}. Stacking of the magnetic traces from MAGSAT passes reveals a magnetic signature (10nT amplitude) at the Churchill-Superior boundary in an area studied between 80°W and 98°W. Modeling suggests a step-like thickening of the crust on the Churchill side of the boundary in a layer with a magnetization of 3 Am^{-1}. Signatures on aeromagnetic maps are also found in the source areas for both of these satellite anomalies. (MAGSAT, anomaly interpretation, precambrian tectonics, Superior boundary, Canada).

J. Geophys. Res., B, Paper 4B1170.

2530 Spatial variations (all harmonics and anomalies)
ON THE IDENTIFICATION OF MAGSAT ANOMALY CHARTS AS CRUSTAL PART OF THE INTERNAL FIELD
J. Meyer (Institut für Geophysik der Universität Göttingen, Herzberger Landstr. 180, 3400 Göttingen Fed. Rep. of Germany), J.-H. Hufen, M. Siebert and A. Hahn

Satellite magnetic anomaly charts are derived from the measurements by subtracting a global field model regarded as representative of the core field, after removal of the external field effects. The field model comprises all spherical harmonic terms of the internal field up to a certain degree n, say n=13. Hence the large-scale constituents of the crustal field are also removed from the anomaly charts. The calculated magnetic field of a global magnetization model of the earth's crust gives an estimate of the lacking lower-order crustal terms. It turns out that the omitted crustal field part is of the same order of magnitude as the rest of the field. The geographic distribution of the omitted model field part on a continental scale is closely correlated with the depth of the Moho. By analogy the same conclusion is drawn with respect to the actual crustal field. This result accounts for the fact that in the satellite charts the continental margins are not very well reflected. Considerable corrections are, therefore, required if the anomaly charts are intended to display the whole crustal field. (Magnetic anomalies, crustal field, satellite charts).

J. Geophys. Res., B, Paper 4B1171.

Hydrology

3110 Erosion and sedimentation
SEDIMENT PRODUCTION FROM FOREST ROAD SURFACES
L. M. Reid and T. Dunne (Dept. Geological Sciences AJ-20, University of Washington, Seattle, WA, 98195)

Erosion on roads is an important source of fine-grained sediment [illegible] the Pacific Northwest. Runoff rates and sediment concentrations from ten road segments subject to a variety of traffic levels were monitored to produce sediment rating curves and unit hydrographs for different use levels and types of surfaces. These relationships are combined with a continuous rainfall record to calculate mean annual sediment yields from road segments of each use level. A heavily used road segment in the field area contributes 130 times as much sediment as an abandoned road. A paved road segment, along which cut-slopes and ditches are the only sources of sediment, yields less than 1% as much sediment as a heavily used road with a gravel surface. (Road-surface erosion, road runoff, forest roads, sediment yield, [illegible])

Water Resour. Res., Paper 4W0944.

3130 Groundwater
A GREEN-AMPT MODEL OF INFILTRATION IN A CRACKED SOIL
Malcolm R. Davidson (CSIRO Division of Mineral Physics, Lucas Heights Research Laboratories, Lucas Heights, N.S.W., 2232, Australia)

The motion of the wetting front in a two-dimensional Green-Ampt model of infiltration into a soil containing regularly spaced water filled vertical cracks is tracked using a stepwise numerical procedure which approximately solves an integral equation for the velocity at points on the front at each time step. Initially, the calculated front exhibits a mushrooming effect at its base which diminishes both with time and as moisture potential becomes more negative. The shape of the front is independent of crack spacing/depth ratio until the interaction of wetting fronts emerging from adjacent cracks. Thereafter, the front becomes flatter and advances further (cumulative infiltration is greater), relative to the crack depth, with decreasing crack spacing and increasingly negative soil moisture potential. (Green-Ampt, infiltration, cracks).

Water Resour. Res., Paper 4W1016.

[illegible]

3170 Snow and Ice
WETTING FRONT ADVANCE AND FREEZING OF MELTWATER WITHIN A SNOW COVER 2. A SIMULATION MODEL
P. Marsh (National Hydrology Research Institute, Environment Canada, Ottawa, Ontario, Canada, K1A 0E7) and M.K. Woo

A simulation model is developed which incorporates the effect of flow fingers at the leading edge of the wetting front, ice layer growth within and at the base of the snow cover, and meltwater infiltration into the underlying frozen soils. The model results demonstrated that ice layers grow rapidly over a 24 to 36 hour period due to the conduction of heat into the snow and underlying soil. Sufficient water is frozen as ice layers to slow the finger wetting front and to account for the rapid snow and soil warming. Wetting front advance and ice layer growth were found to be sensitive to snow temperature, thermal conductivity, volume of flow in the fingers, and irreducible water saturation. Simulation of a warm snow cover showed that with reduced ice layer growth, the flow fingers were able to rapidly transmit water to the snow cover base, before the entire snow cover was wet. In the Arctic situation the soil was sufficiently cold to ensure basal ice growth throughout the melt period. Basal ice growth was found to be sensitive to soil infiltration, length of the growing period and the snowmelt rate. As a result of the negative soil heat flux all meltwater is not available for runoff until both the liquid and thermal requirements of the snow and soil have been satisfied. (snow cover, wetting front, ice layers, simulation model).

Water Resour. Res., Paper 4W1050.

3170 Snow and Ice
WETTING FRONT ADVANCE AND FREEZING OF MELTWATER WITHIN A SNOW COVER 1. OBSERVATIONS IN THE CANADIAN ARCTIC
P. Marsh (National Hydrology Research Institute, Environment Canada, Ottawa, Ontario, Canada, K1A 0E7) and M.K. Woo

In a naturally stratified snow cover, the movement of meltwater into dry snow is complicated by the interaction of the wetting front with stratigraphic horizons. Field observations showed that when the wetting front reached premelt stratigraphic horizons, water ponded at the interface and then flow fingers developed and penetrated the lower stratum. The flux in these fingers, which was increased to about twice that of the surface flux, was used to feed water to the impeding horizons where it froze to form ice layers. These ice layers were the major source of latent heat released within the snow cover and they were responsible for the warming of the snow and the underlying soil. These continuous ice layers grew only at stratigraphic boundaries. Because of this ice layer growth, the wetting front advance was retarded and the arrival of meltwater at the snow cover base was significantly delayed. Due to a cold substrate, the strong heat flux from the snow into the soil delays the warming of the snow cover and limits runoff after the snow is isothermal at 0°C by the refreezing of soil infiltration and the development of a basal ice layer. (snow cover, wetting front, ice layers, Arctic).

Water Resour. Res., Paper 4W1049.

3175 Soil moisture
A CONCEPTUAL MODEL OF DEEP UNSATURATED ZONES WITH NEGLIGIBLE RECHARGE
Benjamin Ross (Disposal Safety Incorporated, 1211 Connecticut Ave. NW, Washington, DC 20036)

When net recharge is less than about 0.03 mm/yr, moisture movement in deep unsaturated zones at steady state will be dominated by upward movement of vapor driven by the geothermal gradient. With zero net recharge, there will be a downward flow of liquid water equal to the upward vapor flux. This will produce a profile of suction potential versus depth qualitatively similar to that expected if recharge is not negligible. Consequently, the existence of a region of uniform potential is not in itself evidence of recharge.

Water Resour. Res., Paper 4W1020.

3180 Water Quality (Sediment-water Interface)
INTERACTIONS OF SOLUTES AND STREAMBED SEDIMENT - Part 1 - AN EXPERIMENTAL ANALYSIS OF CATION AND ANION TRANSPORT IN A MOUNTAIN STREAM
Kenneth E. Bencala (U.S. Geological Survey, [illegible], Menlo Park, [illegible]), Vance C. Kennedy, Gary W. Zellweger, Alan P. Jackman, and Ronald J. Avanzino

An experimental injection was performed to study the transport of streamwater solutes under conditions of significant interaction with streambed sediments in a mountain pool-and-riffle stream. Experiments were conducted in Little Lost Man Creek, Humboldt County, California, in a period of low flow during which only a part of the bankfull channel held active surface flow. The injection of chloride and several trace cations lasted twenty days. In this report we discuss the results of the [illegible]

3180 Water Quality
HYDROLOGIC ANALYSES OF ACIDIC AND ALKALINE LAKES
[illegible]

3199 General (Geothermal Energy)
THE HEBER GEOTHERMAL FIELD, CALIFORNIA: NATURAL STATE AND EXPLOITATION MODELING STUDIES
[illegible]

Meteorology

3750 H_2O in the Atmosphere
SEASONAL VARIATION OF THE GLOBAL WATER BALANCE BASED ON AEROLOGICAL DATA
Frank Bryan (Geophysical Fluid Dynamics Program, Princeton University, P.O. Box 308, Princeton, N.J., 08542), Abraham Oort
The distribution of evaporation minus precipitation over the globe and its seasonal variations are estimated from global atmospheric circulation statistics for the period May 1963–April 1973. Meridional profiles of evaporation minus precipitation over the Atlantic, Pacific, and Indian Oceans, over all oceans combined, all continents combined, as well as the total evaporation minus precipitation over each oceanic and continental region are shown. The Pacific Ocean is found to have an excess of precipitation, and the Atlantic an excess of evaporation throughout the year. Over the Indian Ocean precipitation exceeds evaporation during December–February, while evaporation exceeds precipitation during the rest of the year, and in the annual mean. The results are generally in qualitative agreement with previous estimates of the annual mean world water balance based on surface observations. There are large quantitative discrepancies, however, particularly in the subtropics. A comparison with the analysis of two months of data from the FGGE period suggests that the primary source of error in our results is associated with spatial sampling deficiencies in the general circulation statistics. It appears that, in many regions, the current operational rawinsonde network is inadequate to give reliable quantitative estimates of differentiated quantities, such as are required in computing the atmospheric water balance.

J. Geophys. Res., D, Paper 4D1192.

3770 Technique (Dry Deposition Measurement)
A FIELD INTERCOMPARISON OF METHODS FOR THE MEASUREMENT OF PARTICLE AND GAS DRY DEPOSITION
D. A. Dolske and D. F. Gatz (Illinois State Water Survey, P.O. Box 5050, Station A, Champaign, IL 61820)
Concurrent measurements of the dry deposition of sulfate, particulate sulfur, nitrate, sulfur dioxide, ozone, and nitric acid were made during September 1981 and June 1982 at a site near Champaign, Illinois. Flux determinations were made by micrometeorological methods such as eddy correlation and concentration gradient/modified Bowen ratio, as well as by deposition accumulation methods, using surrogate surface collectors of several types. Researchers from 14 U.S. and Canadian institutions participated in the study. Sulfate and particulate sulfur deposition velocities, Vd on the order of 0.1 cm/s were found by several methods. Strong diurnal variations in particle Vd were noted, with nighttime values near zero and daytime Vd up to 1.0 cm/s for particulate sulfur. Ozone fluxes from several independent measurement methods were in good agreement. Daytime sulfur dioxide and nitric acid Vd of several cm/s were observed, suggesting near-zero vegetation canopy resistance to mass transfer for these gases. (dry deposition, aerosols, gases)

J. Geophys. Res., D, Paper 4D1146.

3790 Instruments and Techniques
A COMPARISON OF US AND USSR ROCKETSONDES USING LIMS SATELLITE TEMPERATURE SOUNDING AS A TRANSFER STANDARD
J. C. Gille, P. L. Bailey and S. A. Beck (National Center for Atmospheric Research[a], Boulder, Colorado 80307)
Temperature soundings from rocketsondes used by the USSR have been compared to temperature retrievals obtained in low, middle and high latitudes by the LIMS instrument on Nimbus 7. The rocket and satellite temperatures agree at low altitudes, but the rocket temperatures are about 10K cooler near the stratopause. There is a tendency for the agreement to become better in the mesosphere, but there appear to be significant differences between day and night comparisons. A day-night correction curve is derived, and the USSR comparisons converted to day conditions. A comparison between LIMS and US rocketsondes in the same latitude bands shows generally good agreement up to the stratopause, but above that the US rocket temperatures are warmer. Then, using the LIMS as a transfer standard, rocketsondes from the US and USSR are intercompared. The differences are similar in all three latitude bands, but larger than those found in the previous (1977) intercomparison. The differences determined in this study should be more representative, since they represent a variety of locations and seasons, as well as standard operational procedures. (Rockets, satellites, temperature, stratosphere.)

[a]The National Center for Atmospheric Research is sponsored by the National Science Foundation.

J. Geophys. Res., D, Paper 4D1176.

3799 General (Planetary Waves)
AN ASSESSMENT OF THERMAL, WIND, AND PLANETARY WAVE CHANGES IN THE MIDDLE AND LOWER ATMOSPHERE DUE TO THE 11-YEAR UV FLUX VARIATIONS
Linwood B. Callis (NASA Langley Research Center, Hampton, Virginia, 23665), Jordan C. Alpert and Marvin A. Geller
A 2-dimensional radiative equilibrium calculation is used to calculate atmospheric temperature changes due to UV flux variations and the associated ozone changes assumed to be due to the 11-year solar cycle. Included are an upper limit case and flux variations suggested by Lean (1984) and Cook et al. (1980). Temperature changes of up to 7°K and zonal wind changes of up to 15 m/s were found. The structure of planetary wave numbers 1 and 2 were calculated with a linear quasi-geostrophic model and shown as a function of latitude and altitude from the surface to 50 km for the northern hemisphere winter. Amplitude changes due to the solar cycle are compared to the reference case and to the extreme interannual variability. Results suggest that tropospheric and lower stratospheric changes would be small and difficult to detect. Middle and upper stratospheric effects are significantly larger and effects should be discernable give a long enough sequence of meteorological data. (UV variability, 11-year solar cycle, planetary waves, climate change).

J. Geophys. Res., D, Paper 4D1191.

Oceanography

4705 Boundary layer and exchange processes.
MEASUREMENTS OF BUBBLES IN A STATIONARY FIELD OF BREAKING WAVES BY A LASER-BASED SINGLE PARTICLE SCATTERING TECHNIQUE
S. Baldy and M. Bourguel (Institut de Mécanique Statistique de la Turbulence, Marseille, France, 13003).
Measurements of the air bubbles generated by breaking waves at a water-air interface have been performed. The measurements were made in a wind-water channel using a single particle (bubble) scattering technique. To avoid the usual ambiguity in this technique about the cross section, an original numerical processing of the scattered intensities, taking advantage of the low particle (bubble) velocities, was used. The bubble concentration probability density and additional informations, such as the crossing frequency, arrival time interval or estimated speed distributions, are then directly available. In the immediate vicinity of the breaking waves, high concentrations of bubbles were observed. The corresponding distribution function has no peak in the diameter range 60–1000μ. This distribution changed significantly with the wave age. The modification of the latter parameter being obtained by considering on the one hand waves generated by the wind flow alone and on the other hand waves produced by the cumulative effects of the wind and a wavemaker. The bubble speed and arrival time additional informations allowed to further notice high fluid estimated velocities and to characterize bubble clusters in the vicinity of breaking waves. Distinctive features of mutually poorly related previous approaches, may be found in this investigation. (Bubbles, particle measurements, breaking waves).

J. Geophys. Res., C, Paper 4C1095.

4740 Marine geological processes (beaches, turbidity currents, sedimentation)
ESTUARINE FLOCS: THEIR SIZE, SETTLING VELOCITY AND DENSITY
R. J. Gibbs (Center for Colloidal Science, College of Marine Studies, University of Delaware, Newark, DE, 19716)
The size and settling velocity of flocs of suspended sediments from the Chesapeake Bay were measured in laboratory experiments and in the field. The curves between floc diameter and settling velocity showed a non-Stoke's relationship that was best described by:
Settling Velocity(cm/sec)=1.73(floc diameter, cm)$^{0.78}$.
Furthermore, the relationship between floc diameter and settling velocity indicated that the floc density decreased as the flocs increased in size. In addition to changing density, a cylinder shape was found to be the best shape factor. (Flocs, estuaries, settling velocity).

J. Geophys. Res., C, Paper 4C1096.

4770 Turbulence and Diffusion
MOMENTUM TRANSPORT IN THERMOHALINE STAIRCASES
Barry R. Ruddick (Department of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada B3H 4J1
Given the fine scale temperature and salinity in an actively convecting thermohaline staircase, can the average eddy viscosity be estimated? A simple model for momentum transport in such a system shows that the average dissipation and viscosity are controlled by the regions of high dissipation and small eddy viscosity; i.e., the interfaces. The model results are combined with a mechanistic argument for momentum transport across the interfaces by convection-driven internal waves. The average eddy viscosity for the staircase is about 40 J_b/N^2, where J_b is the buoyancy flux, and N the buoyancy frequency. By definition the eddy diffusivity of the staircase is $-J_b/N^2$ and so the turbulent Prandtl number is constant and equal to −40. The model predictions are consistent with dissipation measurements in the Bahamas by Larson and Gregg (1983) and imply eddy viscosities of about 10^{-3}m²/s. (Eddy viscosity, double diffusion, convection, Reynolds stress, internal waves)

J. Geophys. Res., C, Paper 4C1129.

4799 (Hydrothermal)
HYDROTHERMAL ACTIVITY AT THE TAG HYDROTHERMAL FIELD, MID-ATLANTIC RIDGE CREST AT 26°N
P. A. Rona (NOAA/AOML, 4301 Rickenbacker Causeway, Miami, Florida 33149), G. Thompson, M. J. Mottl, J. A. Karson, W. J. Jenkins, D. Graham, M. Mallette, K. Von Damm, and J. M. Edmond
The first submersible observations of the only known active submarine hydrothermal field on a slow-spreading oceanic ridge are incorporated with results of ten prior years of investigation to derive an understanding of periodicity, duration, and varying intensity of hydrothermal activity at the TAG Hydrothermal Field on the Mid-Atlantic Ridge crest near latitude 26°N. Hydrothermal activity has persisted at this location for at least 1 x 10^5y based on the distribution of hydrothermal and hydrogenous mineralization with respect to crustal age. The hydrothermal activity has been cyclic, multi-stage, and episodic. Prior high-temperature hydrothermal venting stages with a periodicity of the order of 1 x 10^4y and duration of the order of 10^1y are deduced from the estimated ages of discrete sedimentary layers anomalously enriched in Cu, Fe, and Zn, and correspond with the independently determined periodicity of volcanic eruptive cycles on the Mid-Atlantic Ridge. The most recent episode of high-temperature venting is inferred to have ceased in the recent past based on metal enrichment (Cu, Fe, Zn) in the surficial sediment layer. Low-temperature hydrothermal venting stages with a duration of the order of 1 x 10^4y intervene between the short high-temperature stages and produce stratiform deposits of layered and earthy manganese oxide, iron oxide, hydroxide and silicate. Bivalve-like forms with the characteristics of vent clams in various stages of dissolution are identified on bottom photographs. The fresh appearance of intact tubules composed of iron hydroxide that acted as vents on relict deposits, conductive heat flow anomalies in the sediment column, and the record of temperature anomalies and excess ^{3}He in the near-bottom water column, suggest that the low-temperature hydrothermal discharge is intermittent at individual vents on a time scale of years.

J. Geophys. Res., B, Paper 4B1038.

Particles and Fields—Interplanetary Space

5340 Shock Waves
EFFECTS OF ELECTRON PRESSURE ON QUASI-PARALLEL COLLISIONLESS SHOCKS
H. B. Mandt (Geophysical Inst., U. of Alaska, Fairbanks, Alaska, 99701) and J. R. Kan
The effects of a finite electron pressure on quasi-parallel collisionless shocks are examined by means of numerical simulations. The simulation is performed using a non-periodic, hybrid code in which the ion dynamics are followed exactly and the electrons are treated as a massless fluid of finite pressure. The results of the simulations show that the electron pressure significantly improves the stationarity of the shock structure. The finite electron pressure also leads to an electrostatic potential across the shock as expected. The potential structure is localized and stable at low Alfvén mach number (M_A=2), but for higher mach number (M_A=4) it is non-local and unstable. In either case the change in potential energy is on the order of the downstream electron parallel thermal energy. Power spectral analysis of the upstream waves shows that they are right-hand polarized whistlers, phase standing in the shock frame. (Shocks, whistler precursors).

J. Geophys. Res., A, Paper 4A8127.

5340 Interplanetary Space (Shock Waves)
ON THE DISTRIBUTION OF θ_{Bn} FOR SHOCKS IN THE SOLAR WIND
Jih K. Chao (Department of Atmospheric Physics, National Central University, Chung-Li, Taiwan) and Yin H. Chen
Presented at the Chapman Conference on "Collisionless Shock Waves in the Heliosphere"
The distribution of the shock normal angles, θ_{Bn} can be calculated for all the heliocentric distances when the distributions of $\vec{n}$ and $\vec{B}$, are available where θ_{Bn} is the angle between the upstream magnetic field $\vec{B}$, and the normal shock $\hat{n}$. The average shock normal is assumed to propagate approximately in the radial direction. However, the distribution of the angles θ_{nr}, between the shock normals and radial direction is assumed to follow a Rayleigh distribution. The distribution of $\vec{B}$, is obtained by observations by Helios 1, 2, Voyager 1 and Pioneer 10 spacecraft. The distribution of each component of $\vec{B}$, is assumed to follow a Gaussian.
Our results show that even very close to the sun, the probability of observation of parallel and quasi-parallel shocks is still smaller compared to the observation of quasi-perpendicular and perpendicular shocks. Therefore, it is concluded that the parallel and quasi-parallel shocks do not easily form in the solar wind because of the fluctuating character of $\vec{B}$, and $\hat{n}$ and not because of any other physical mechanism.
The observed distributions of θ_{Bn} using Helios 1 and 2 at heliocentric distances between 0.3 to 0.5 AU, 0.5 to 0.75 AU and 0.75 to 1.0 AU are compared with our calculated distributions. The agreement is good, with the agreement at 0.75 to 1.0 AU being the best. The comparison is also made with the results from ISEE 3 observations at 1 AU. Our calculated distribution agrees very well with these observations.

J. Geophys. Res., A, Paper 4A1133.

Particles and Fields—Ionosphere

6635 Interactions between waves and particles
VARIABLE-FREQUENCY VLF SIGNALS IN THE MAGNETOSPHERE; ASSOCIATED PHENOMENA AND PLASMA DIAGNOSTICS
C. R. Carlson (Space, Telecommunications and Radioscience Laboratory, Stanford University, Stanford, CA 94305), R. A. Helliwell, and D. L. Carpenter
Coherent variable-frequency signals (ramps) extending from 1 to 8 kHz, injected into the magnetosphere from Siple Station, Antarctica (L=4.3), exhibit upper and lower cutoffs when received at the conjugate station, Roberval, Quebec. Ramp group delay measurements and ionospheric sounding data are used for the first time to determine the cold plasma density and L shell of the propagation path. Relationships among f, df/dt, and the 'phase equator' for gyroresonance are calculated using second order resonance equations generalized to relativistic electrons. Observed upper cutoff characteristics are interpreted in terms of off-equatorial gyroresonant interaction regions and ducted propagation limited to frequencies below half the local gyrofrequency. The observed lower cutoff frequencies varied systematically with transmitted ramp slope, suggesting a threshold in the resonant electron number density above which rapid temporal wave growth and saturation can occur. This concept is used to develop a hot plasma diagnostic technique which, for an assumed g(α)v^{-n} electron distribution, provides an estimate of the energy dependence n. A test of this technique is given using the data and a simplified wave-particle interaction simulation. Additional aspects of the magnetospheric response to ramp injection, including emission triggering, are discussed. (VLF experiments, whistler-mode propagation, magnetospheric plasma diagnostics, wave growth).

J. Geophys. Res., A, Paper 4A1186.

5535 Interactions between waves and particles
DIRECT EVIDENCE FOR TWO-STAGE (BIMODAL) ACCELERATION OF IONOSPHERIC IONS
D. M. Klumpar[a], W. K. Peterson, and R. D. Shelley (Space Sciences Laboratory, Lockheed Palo Alto Research Laboratory, 3251 Hanover Street, Palo Alto, California 94304)
New measurements from the Energetic Ion Composition Spectrometer on the Dynamics Explorer-1 satellite reveal the existence of hybrid conical distributions which are interpreted as the first direct observation of a two-stage acceleration of ionospheric ions. The ions display characteristics of having experienced both transverse and parallel acceleration in the process of being injected into the magnetosphere. This signature consists of field alignment of the ions at energies just above a lower energy cutoff below which no fluxes are measured. At increasing energy the field-aligned distribution gradually becomes a conical one whose apex angle widens with increasing energy. The lower energy cutoff gradually increases and then decreases as the satellite moves in latitude in a manner like that found in ion inverted V's. In one case analyzed in detail transversely accelerated oxygen ions having energies to 5 keV were observed while the lower energy ions were primarily field-aligned between 430 and 870 eV. It is concluded that ions were accelerated from the ionospheric plasma by a mechanism acting primarily transverse to the geomagnetic field at an altitude near 18,000 km and additionally accelerated through a parallel potential that exceeded 300 volts in the core of the inverted-V. The heating mechanism produced a bi-Maxwellian distribution of oxygen ions with transverse and parallel temperatures of −1.2 keV and −260 eV, respectively. The deduced 0^+ density was on the order of 0.5 cm^{-3} in the source. (Ionosphere-magnetosphere coupling, auroras, particle acceleration, ion composition)
[a]on leave from the University of Texas at Dallas

J. Geophys. Res., A, Paper 4A8024.

5580 Wave Propagation
THE PLASMA WAVE ENVIRONMENT OF AN AURORAL ARC: 2. ULF WAVES ON AN AURORAL ARC BOUNDARY
C. G. Gelpi (Dept. of Astronomy, Boston University, Boston, MA 02215) and E. A. Boring
On March 9, 1978 a sounding rocket launched from Poker Flat, Alaska at 2200 LT, made a 4-component measurement of a .5 Hz hydromagnetic wave as the payload crossed the poleward boundary of a quiet homogeneous auroral arc. An energy flux of ~ 10^{-6} watts/m² was observed propagating upward with a left-handed polarization within the arc and a flux six times greater was observed propagating downward with a right-handed polarization on the arc boundary. The waves were identified as shear mode Alfven waves. Various models for the source of the free energy are discussed with the conclusion that the most likely production mechanism was either the electromagnetic or electrostatic Kelvin-Helmholtz instability.

J. Geophys. Res., A, Paper 4A1112.

Particles and Fields—Magnetosphere

5736 Magnetic tail
ASSOCIATION BETWEEN ENERGETIC PARTICLE BURSTS AND BIRKLAND CURRENTS IN THE GEOMAGNETIC TAIL
A. T. Y. Lui (Applied Physics Laboratory, The Johns Hopkins University, Laurel, Maryland 20707), S. M. Krimigis.
IMP-8 observations in the geomagnetic tail of energetic particles at hundreds of keV and of magnetic field are examined for a substorm period from 17 to 18 UT on March 3, 1976. For this interval, it is found that bursts of energetic protons detected at a downstream distance of ~ 37 R_E in the midnight tail region are accompanied by east-west magnetic field perturbations indicative of Birkeland current sheets. The magnitude of the magnetic field perturbations ranges from ~1 to 12 nT, corresponding to current densities of 1 to 9 mA/m when integrated over the current sheet thickness. These values are comparable with previous observations of Birkeland currents in the near-earth tail (X > − 20 R_E) and with the auroral-arc-associated Birkeland current densities at low altitudes scaled out to the tail region. The favorable comparison suggests that the closure of small-scale Birkeland current systems, at least in these instances, lies tailward of ~ 40 R_E. The observed Birkeland current system and the magnitude of current densities are found to be consistent with the tearing instability in the tail. The inferred wavelength of the tearing mode along the tail axis is ~ 2 to 17 R_E. In the context of the tearing model, the presence of Birkeland currents and the occasional isotropic distribution of energetic electrons (E_e > 0.22 MeV) in this study suggest that the energetic particle events in this study occur on closed magnetic field lines even though strong tailward-streaming dominates the particle anisotropy in these events. (Magnetic tail, energetic particle anisotropy, field aligned current, tearing mode).

J. Geophys. Res., A, Paper 4A8101.

5739 Magnetopause
TRANSMISSION OF MAGNETOHYDRODYNAMIC WAVES THROUGH THE ROTATIONAL DISCONTINUITY AT THE EARTH'S MAGNETOPAUSE
Y. C. Kwok and L. C. Lee (Geophysical Institute, and Department of Space Physics and Atmospheric Sciences, University of Alaska, Fairbanks, Alaska 99701)
Reflection and transmission of small amplitude magnetohydrodynamic (MHD) waves of solar-wind origin through the Earth's open magnetopause are studied. The open magnetopause with a nonzero normal component of magnetic field is assumed to be a rotational discontinuity. For any type of the incident wave, there is one reflected wave (fast magnetosonic wave) and five transmitted waves (one fast magnetosonic wave, two slow magnetosonic waves, one Alfvén wave and one entropy wave). In this paper, cases with different incident waves, i.e., Alfvén wave, fast magnetosonic wave, forward slow magnetosonic wave and entropy wave are studied. It is found that depending on the type of incident wave, the incident angle and the orientation of the ambient magnetic field, the amplitudes of the emanating waves can be amplified. The research findings also suggest that the transmission of MHD waves across the rotational discontinuity at the Earth's magnetopause can be an important mechanism for the energy transfer from the solar wind into the magnetosphere.

J. Geophys. Res., A, Paper 4A1150.

5155 Plasma Instabilities
DRIFT COMPRESSIONAL INSTABILITY IN THE MAGNETOSPHERE
P. H. Ng, V. L. Patel (Department of Physics, University of Denver, Denver, Colorado 80208), S. Chen (Department of Physics, Liaoning University, Shenyang, People's Republic of China)
The properties of the drift compressional instability in the magnetosphere with a two-component plasma are examined by using gyrokinetic theory. A dipole field is used to approximate the equilibrium geomagnetic field. In contrast to the slab model it is found that electrons of the hot component have a stabilizing effect on the mode excited by the protons. With appropriate values of various parameters, the wave periods in the range of 30–300s are obtained from numerical calculations of the model. The drift compressional instability may provide possible explanation of the compressional waves observed in the magnetosphere.

J. Geophys. Res., A, Paper 4A1150.

5755 Plasma instabilities
FORMATION OF ION ACOUSTIC SOLITARY WAVES UPSTREAM OF THE EARTH'S BOW SHOCK
M. J. Pangia, N. C. Lee and G. K. Parks (Geophysics Program, AK-50, University of Washington, Seattle, WA 98195)
The turbulent plasma development of Lee and Parks is applied to the solar wind approaching the earth's bow shock region. The ponderomotive force contribution is due to ion acoustic waves propagating in the direction of the ambient magnetic field. In this case, the envelope of the ion acoustic wave is shown to satisfy the cubic Schroedinger equation. Modulational instabilities exist for waves in the solar wind, thereby predicting the generation of solitary waves. This analysis further identifies the ion acoustic waves which exhibit this instability have short wavelengths. (Solitary waves, ion acoustic, ponderomotive force).

J. Geophys. Res., A, Paper 4A8126.

5755 Plasma Instabilities
FAST MAGNETOSPHERIC ECHOES OF ENERGETIC ELECTRON BEAMS
E. Wilhelm (Max-Planck-Institut für Aeronomie, D-3411 Katlenburg-Lindau, FRG), W. Bernstein, P.J. Kellogg and B.A. Whalen
Electron beam experiments using rocket-borne instrumentation have confirmed earlier observations of fast magnetospheric echoes of artificially injected energetic electrons. A total of 234 echoes have been observed in a pitch angle range from 9° to 110° at energies of 1.87 and 3.90 keV. Out of this number, 95 echoes could unambiguously be identified with known accelerator operations at 2, 4 or 8 keV energy and highest current levels resulting in the determination of transit times of typically 300 to 400 ms. In most cases, when echoes were present in both energy channels, the higher energy electrons led the lower energy ones by 50 to 70 ms. Adiabatic theory applied to these observations yields a reflection height of 3000 to 4000 km. An alternative interpretation is briefly examined and its relative merit in describing the observations is evaluated. The injection process is discussed in some detail as the strong beam-plasma interaction that occurred near the electron accelerator appears to be instrumental in generating the source of heated electrons required for successful echo detection for both processes. (Artificial electron beams, fast magnetospheric electron echoes).

J. Geophys. Res., A, Paper 4A8147.

5760 Plasma motion, convection, or circulation
A SIMPLE MODEL FOR POLAR CAP CONVECTION PATTERNS AND GENERATION OF θ-AURORAS
L. R. Lyons (Space Science Laboratory, NASA Marshall Space Flight Center, Huntsville, Alabama, 35812)
The simple addition of a uniform interplanetary magnetic field and the Earth's dipole magnetic field is used to evaluate electric field convection patterns over the polar caps that result from solar wind flow across open geomagnetic field lines. This model is found to account for observed polar-cap convection patterns as a function of the interplanetary magnetic field components B_y and B_z. In particular, the model offers an explanation for sunward and antisunward convection over the polar caps for B_z > 0. Observed field-aligned current patterns within the polar cap and observed auroral arcs across the polar cap are also explained by the model. In addition, the model gives several predictions concerning the polar cap that should be testable. Effects of solar wind pressure and magnetospheric currents on magnetospheric electric and magnetic fields are neglected. That observed polar cap features are reproduced suggests that the neglected effects do not modify the large-scale topology of magnetospheric electric and magnetic fields along open polar cap field lines. Of course, the neglected effects significantly modify the magnetic field geometry, so that the results of this paper are not quantitatively realistic and many details may be incorrect. Nevertheless, the model provides a simple explanation for many qualitative features of polar cap convection.

J. Geophys. Res., A, Paper 4A1139.

5770 Short period variations of magnetic field
CONCERNING THE STRUCTURE OF PI2 PULSATIONS
D.J. Southwood (Blackett Laboratory, Imperial College, London, SW72AZ, UK), W.J. Hughes (Department of Astronomy, Boston University, Boston, MA 02215, USA)
We look at some simple theoretical considerations relevant to the origin of PI2 geomagnetic pulsations observed on the ground with the onset of geomagnetic activity. Using a basic model we examine how subsidiary current flows are created by auroral ionospheric conductivity enhancements in the electrojet regions. The current flows, which include field-aligned currents, are associated with reflected shear Alfven waves localised to the field lines which thread ionospheric conductivity gradients. Thus the ionosphere can create distinct latitudinal structure in the signal. We discuss the origin of the observed polarization pattern and predominantly westward phase propagation of PI2 pulsations in the light of our results. We conclude that a superposition of two travelling waves of differing amplitude is required to produce these characteristics.

J. Geophys. Res., A, Paper 4A1165.

5775 Trapped Particles
VOYAGER 1OH PHASE SPACE DENSITIES
N. T. Paonessa (The Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, 20707)
Data from the Voyager Low Energy Charged Particle Experiment (LECP) were used to calculate ion phase space densities in Jupiter's magnetosphere. Calculation of F at constant μ and J_2 requires determinations of particle fluxes at specific pitch angle and energy. It is shown that the greatest uncertainties in the determination of F from LECP data arise from the fits to the measured pitch angle distributions and differential energy spectra. An estimate is provided of this uncertainty and others arising from model radial diffusion coefficients and magnetic fields. The general nature of the curves is consistent with inward diffusion of these energetic ions from the outer magnetosphere, combined with losses near but starting beyond the orbit of Io. These losses are not consistent with simple satellite sweeping by Io alone, and are probably due to an Io torus wave-particle interaction. The lifetime against loss deduced from the data is ~2 x 10^4 seconds near Io, consistent with strong diffusion losses. The measured ion loss rate declines much more rapidly than the strong-diffusion loss rate between as L increases from L = 7 to L = 9 suggesting that the loss rate is well below the strong diffusion rate beyond 7 R_J for ions observed by the LECP.

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5799 General (Magnetospheric ion sources)
ESCAPE OF SUPRATHERMAL O^+ IONS IN THE POLAR CAP
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Instruments onboard the Dynamics Explorer (DE) 1 and 2 spacecraft have been used to investigate the characteristics of a very low energy (less than 10 eV) outflow of O+ ions at high altitudes over the polar cap. The measured O+ outflow has a relatively high mach number (2–6) and a large flux (~2 x 10^8cm^{-2}s^{-1}). A statistical study using 50 orbits of Retarding Ion Mass Spectrometer (RIMS) data indicate that the outflows occur during active magnetic conditions, lasting for several hours over large areas of the polar cap. The observations are then discussed and analyzed in a framework based on polar wind models with particular attention paid to the new information obtained by the DE 2 Fabry-Perot Interferometer (FPI), and the impact these flows have on the composition of the magnetosphere. The observed suprathermal outflow of O+ suggests a scenario requiring both significant compositional changes in the high latitude thermosphere and significant heating of the ions and electrons in the topside ionosphere. (Magnetosphere ion source, particle measurements).

J. Geophys. Res., A, Paper 4A8182.

5799 General (magnetospheric substorms)
OBSERVATIONS OF MAGNETIC FIELD PERTURBATIONS AT GOES 2 AND GOES 3 DURING THE MARCH 22, 1979 SUBSTORMS: CDAW-6 ANALYSIS
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The GOES 2 and GOES 3 satellite high resolution magnetometer data are examined for the March 22, 1979 substorm interval selected by the CDAW 6 Analysis. Both GOES satellites were on the geographic equator with GOES 2 at 104 degrees west geographic longitude and GOES 3 at 135 degrees west geographic longitude. From the comparison of the two GOES magnetometer data sets, the spatial and temporal characteristics of the substorm-associated variations in the geomagnetic field near synchronous orbit are studied. The onset of the first substorm (expansion phase) was observed at GOES 3 at 1053 UT, and at GOES 2 at 1110 UT about 17 minutes later. At this time, GOES 3 was at 0200 LT and GOES 3 was at 0400 LT. Prior to the expansion phase, both GOES satellites detected a growth phase during which the field was distended tailward, and the azimuthal component underwent a negative (westward) excursion. The growth phase began almost simultaneously at the two satellites. During the second substorm, the two satellites did not observe clear substorm signatures because they were at dawn. The magnetic field observations for the first substorm are characterized by the current wedge model proposed by McPherron et al. (1973). (Particles and fields, magnetospheric substorms, CDAW-6).

J. Geophys. Res., A, Paper 4A1183.

5799 General (Dust Charges)
PLASMA POTENTIAL AND GRAIN CHARGES IN A DUST CLOUD EMBEDDED IN A PLASMA
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We have calculated the plasma and dust potential throughout the border region of semi-infinite dust clouds embedded in a plasma. A relevant ordering parameter is P = aN_{do}/N_o (dust radius (in microns) x interior dust density/exterior plasma density). For high dust densities (P > 10^{-3}) the cloud potential is high, screening out electrons, with low interior dust charges as a result. For decreasing P the cloud potential becomes less, with a corresponding increase in the dust charges. At P < 10^{-5} the cloud potential is practically zero and the dust particles have their maximum charge which is identical to that of a single dust particle in a plasma. For diffuse dust cloud border regions with density scale length much larger than the Debye length, the deviations from charge neutrality are small. When the scale length is comparable to or smaller than the Debye length large deviations from charge neutrality occur in the border region. (Dust charges, planetary rings).

J. Geophys. Res., A, Paper 4A8192.

5799 General or miscellaneous
PERTURBATIONS IN THE VELOCITY DISTRIBUTIONS IN A COLLISIONLESS PLASMA
J. W. Dungey (Physics Department, Imperial College, London)
A range of phenomena important in space plasmas calls for simulation and can be approximated by the two-dimensional geometry in which the magnetic field lines are straight and parallel and all gradients are perpendicular to the field. The design of simulations itself motivates analytical theory, in this case linear theory for a velocity distribution. A general formulation of linear theory with the unperturbed state stratified uses the methods of Robertson et al. (1981), the constants of the motion being energy V and canonical momentum P_y. This is developed using the periodicity of any particle trajectory, leading to a simple condition determining the direction of energy exchange between resonant particles in an element dVdP$_y$, and a wave, which is a generalization of the energization of a wave by an overtaking beam. A Larmor radius expansion is performed including the second harmonic of the trajectory frequency, but no higher harmonics, and including the gradient of the electric field, which would be essential for Kelvin-Helmholtz instability. The objective is to determine the dependence of the perturbations on gyrophase. The important result is that the third Fourier component is of second order in the Larmor radius and the formulae are obtained for the Fourier components up to the second. When the Larmor radius expansion is valid, fine structure in the velocity distribution arises only from resonances. A less rigorous discussion of the opposite case, treating the magnetic field as weak, shows that particles faster than the phase speed pass through resonance in the sense of stationary phase. This generally dominates the perturbations, and generally these vary rapidly with gyrophase.

J. Geophys. Res., A, Paper 4A8000.

Planetology

6640 Interior of Moon (composition)
MAGNESIAN ANORTHOSITES AND ASSOCIATED TROCTOLITES AND DUNITE IN APOLLO 14 BRECCIAS
M.M. Lindstrom (Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130.), S.A. Knapp, J.W. Shervais and L.A. Taylor
Magnesian anorthosite, a new type of pristine lunar highlands rock, has been found in Apollo 14 breccias. It has primitive (high Ca and Mg) silicate mineral compositions, and high and variable REE concentrations. Variations in REE contents can be accounted for by variations in modal abundance of REE-rich apatite. Magnesian anorthosites are associated with troctolites and a dunite with very similar mineral compositions and it is suggested that all crystallized from a differentiated troctolitic intrusion. The origin of the REE-rich apatite is enigmatic. It is unlikely to have crystallized from an igneous liquid in equilibrium with the major minerals in the anorthosite. Possible origins are assimilation of urKREEP or metasomatism by REE-rich fluids. REE-rich alkali anorthosites and gabbronorites are also found and are likely to be related to KREEP basalt magmas. Lunar compositional associations are distributed in a regional rather than global manner. (Apollo 14, pristine rocks, phosphates, rare earth elements).

J. Geophys. Res., B, Paper 4B5833.

6640 Interior of Moon (composition)
ALKALI GABBRONORITE, ULTRA-KREEPY MELT ROCK AND THE DIVERSE SUITE OF CLASTS IN NORTH RAY CRATER FELDSPATHIC FRAGMENTAL BRECCIA 67975
M.M. Lindstrom (Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130)
Lunar breccia 67975 is a feldspathic fragmental breccia from North Ray crater, Apollo 16. It contains clasts of alkali gabbronorite and ultra-KREEPy mafic fragmental-like [illegible] Apollo 16 samples. [illegible] rocks with moderate to high REE concentrations. They more strongly resemble Apollo 14 gabbronorites and alkali anorthosites and KREEP-rich rocks than they do other Apollo 16 samples. The other clasts in 67975 are the ferroan anorthosites, feldspathic melt rocks, and magnesian granulites, which are typical of other feldspathic fragmental breccias. Examination of bulk and mineral compositions of other breccias and melt rocks suggests that alkali gabbronorite may be a minor component in other North Ray crater breccias and feldspathic melt rocks. This implies that alkali gabbronorite was a fairly early (4.0 b.y.) crustal component in the North Ray crater region. (Apollo 16, breccias, pristine rocks, rare earth elements).

J. Geophys. Res., B, Paper 4B5832.

6360 Meteorites
PETROGRAPHIC STUDIES OF REFRACTORY INCLUSIONS FROM THE MURCHISON METEORITE
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Mineralogical and petrographic data are presented for ten refractory inclusions recovered by freeze-thaw disaggregation and heavy liquid separation from the Murchison C2 chondrite. One hibonite-, corundum-rich and two hibonite-spinel inclusions are completely unlike any previously described objects. The corundum-bearing inclusion has a hibonite core that is partially replaced by corundum, which is itself partially replaced by hibonite. It formed either by condensation during varying physico-chemical conditions or by partial incongruent melting of hibonite at ≈2100°K to form corundum and liquid, followed by distillation of calcium from the melt and reaction of the residual liquid with some of the corundum upon cooling. The melting temperature required in the latter model is far above astrophysical estimates of nebular temperatures, except perhaps at the very center of the nebula. The hibonite-spinel inclusions are beautiful lacy aggregates of euhedral hibonite plates, some of which were pseudomorphically replaced by spinel. Textures provide compelling evidence of a vapor-solid condensation origin and clearly show that spinel formed by direct reaction of hibonite with the solar nebular gas, without the intervention of $CaAl_2O_4$ and prior to condensation of melilite, in conflict with equilibrium thermodynamic calculations. Four blue hibonite-spinel spherules are described, three of which differ from all previously studied members of this class in being intensely altered to phyllosilicate and calcite. One shows evidence of two stages of alteration to phyllosilicates, possibly one in the solar nebula and the other in the parent body. Two of three pyroxene-, spinel-, forsterite-rich inclusions described herein differ from previously studied members of this group, one in containing a peculiar amoeba-shaped spinel-pyroxene core suggestive of a vapor-solid condensation origin and the other in containing a spheroidal core suggestive of crystallization from a melt. The Murchison parent body sampled materials that formed under a wide range of nebular conditions and contains many objects composed of more refractory phase assemblages than are found in most Allende inclusions. (Solar nebula, carbonaceous chondrites, condensation, refractory inclusions).

J. Geophys. Res., B, Paper 4B5825.

6570 Surface of Moon
APOLLO 16 SITE GEOLOGY AND IMPACT MELTS: IMPLICATIONS FOR THE GEOLOGIC HISTORY OF THE LUNAR HIGHLANDS.
P. D. Spudis (U.S. Geological Survey, 2255 North Gemini Drive, Flagstaff, Arizona 86001)
The Apollo 16 mission provided direct samples of two lunar highlands geological units: the Descartes and Cayley Formations. The Descartes Formation is interpreted as hummocky Nectaris basin ejecta, reworked by secondary impacts from the Imbrium basin. The Cayley Formation was emplaced as a consequence of the Imbrium impact and incorporated large quantities of the local substrate, which in this region consists mostly of Nectaris ejecta. The composition of the upper crust in this area is primarily anorthositic gabbro; local craters near the site would produce an impact melt of this composition. I estimate the total volume of pure melt within the Apollo 16 site deposits to be about 10% or less, significantly smaller than previous estimates. Two chemically defined melt groups found at Apollo 16 are of broadly low-K Fra Mauro (LKFM) basaltic composition and could not be produced by local craters in the region. The volumetrically most important melt group at Apollo 16 is of aluminous LKFM composition and appears to have formed in one event at 3.92 AE; these rocks probably represent Nectaris basin impact melt. Imbrium basin impact melt may also be present, in quantities of less than 1%. The model presented here suggests that the Descartes Formation (Nectaris ejecta) is a two-component mixture of anorthositic clastic debris (≈90% by volume) laden with aluminous LKFM Nectaris basin impact melt (≈10% by volume). If the age of the Nectaris basin is 3.92 AE as suggested, then there is probably no in situ primordial surface dating from the time of crustal formation, and the total thickness of the highlands "megaregolith" may be greater than a factor of ten higher than the currently quoted value (1–2 km). (Apollo 16 site, impact melts, Nectaris basin).

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6570 Surface of Moon
COMPOSITION OF ORIENTALE BASIN DEPOSITS AND IMPLICATIONS FOR THE LUNAR BASIN-FORMING PROCESS
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The Orientale basin, on the lunar western limb, has served as the prototype lunar multi-ring basin for many years. In order to constrain possible models of the formation and excavation of basin ejecta, we have studied the composition of Orientale basin deposits, using both earth-based spectral reflectance and Apollo orbital geochemical data. Results indicate that Orientale basin ejecta are dominantly anorthositic with compositions ranging from pure anorthosite to noritic anorthosite. Although minor quantities of mare basalt and low-K Fra Mauro basalt are present, ultramafic and KREEP components appear to be absent. Portions of the inner rings of the basin may be composed of anorthosite whose shock levels exceed 20 Gpa (200 kb). In conjunction with photogeologic evidence for the preservation of prebasin topography and structure within the Cordillera basin ring, we suggest that the diameter of the excavation crater of the Orientale basin is on the order of 500 to 600 km. Effective depths of excavation are probably less than about half the local crustal thickness, which in this region is on the order of 100 km. We find that the Orientale impact excavated dominantly upper crustal rocks with a depth of excavation consistent with a proportional-growth, basin-forming model. (Orientale basin, ejecta, composition, basin formation).

J. Geophys. Res., B, Paper 4B5819.

6575 Surface of planets (Mars)
QUANTIFICATION OF WASTE MORPHOLOGY IN MARTIAN FRETTED TERRAIN
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Extensive geomorphic mapping in the northern Martian fretted terrain of Deuteronilus and Protonilus Mensae shows details of the waste-dominated landform association in this region. Mass wasting appears to have occurred along the cratered terrain boundary (CTB) at the expense of old cratered terrain. North of the boundary remnants of old cratered terrain occur as island mesas surrounded by extensive debris aprons. Quantitative study using principal components analysis (PCA) reveals distinct spatial variations in the morphology of waste forms in the region and supports the qualitative interpretations made during geomorphic mapping. These organized spatial patterns occur with respect to longitude and latitude, and therefore with reference to distance from the CTB, and provide clues to the degradational history of the region. Analyses of individual landforms irrespective of their location to the CTB suggests strong structural control of their form. Mesas seem to have evolved from equant forms to narrow ridges with large debris aprons after they were detached from old cratered terrain. The success of PCA in explaining patterns in the degradational landforms suggests that PCA may be an important technique useful in quantifying the geomorphic evolution of the Martian surface. (Mars, surface morphology, fretted terrain, principal components analysis).

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